Assessment of Markets for Fiber and Steel Produced From Recycling Waste Tires

August 2003

Integrated Waste Management Board

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Executive Summary

The processing of crumb rubber from waste tires produces steel and fiber by-product streams that, in many cases in California, must be disposed of due to lack of market demand. The cost of disposing these materials raises the cost of processing and lowers the profitability of waste tire recycling. Thus, the recycling of waste tires could benefit from development of markets and increased demand for tire-derived steel and fiber.

Approximately 33 million waste tires were generated in California in 2001, according to the California Integrated Waste Management Board (*Waste Tire Management Program: 2001 Staff Report*, 2003, p. 8). During the same year, an estimated 8 million tires were processed for recovery and recycling of crumb rubber, and approximately 75 percent of waste tires overall were diverted from land disposal. Thus, while the diversion rate for waste tires is substantial, there is room for improvement.

Results and Status

To define the status of recycling of tire-derived steel and fiber, CalRecovery, Inc. performed an in-depth analysis of issues related to the marketability of these two materials. Background data and information were collected in a survey of waste tire processors, the tire industry, and the marketplace. The information was evaluated, resulting in a number of findings and recommendations.

The potential supply of recoverable steel and fiber in California in 2002 is estimated to have been in the range of 14,000 to 61,000 tons and 9,000 to 39,000 tons, respectively. The lower value of the ranges results from the consideration of crumb rubber processing only; the higher value of the ranges is the quantity of by-product that would have been generated if all waste tires in 2002 were processed for recovery.

Regarding by-product management, among all processors surveyed worldwide, approximately 61 percent are disposing of fiber rather than recycling it (48 responses of 79), while 38 percent indicated that steel was not being recycled (27 responses of 72).

At the time of the survey, at least three California processors were recycling bead steel, and at least two were recycling belt wire. Forty-three percent of the California tire processors reported no market for tire-derived steel (3 responses of 7). With regard to fiber, one California processor reported selling fiber for a fiber tire-derived fuel (TDF) application.

Based upon all of the industry contacts, only one steel and four fiber commercial applications were found that used tire-derived materials. The number of firms actively participating in the waste tire by-product marketplace is a small fraction of the more than 800 firms contacted in the processor and end-use groups. Of the 206 responding to the survey from the processors group, fewer than 15 percent reported that they separated and recycled steel and fewer than 3 percent reported separating and recycling fiber.

Table 1 shows a comparison of percentage of processors recycling tire-derived steel and fiber.

Table 1. Percentage of Processors Recycling Tire-Derived Steel and Fiber

Location	Percent[a]		Counts	
	Steel	Fiber	Steel	Fiber
California	36.0	38.5	13	13
Rest of U.S.	59.4	40.4	55	57
International	78.9	33.3	10	9
Totals	**58.0**	**39.2**	**78**	**79**

[a] Percentage of respondents that reported recycling rather than disposing of tire-derived steel or fiber.

Estimates of potential and existing diversion of steel and fiber from waste tire processing in California are shown in the Table 2.

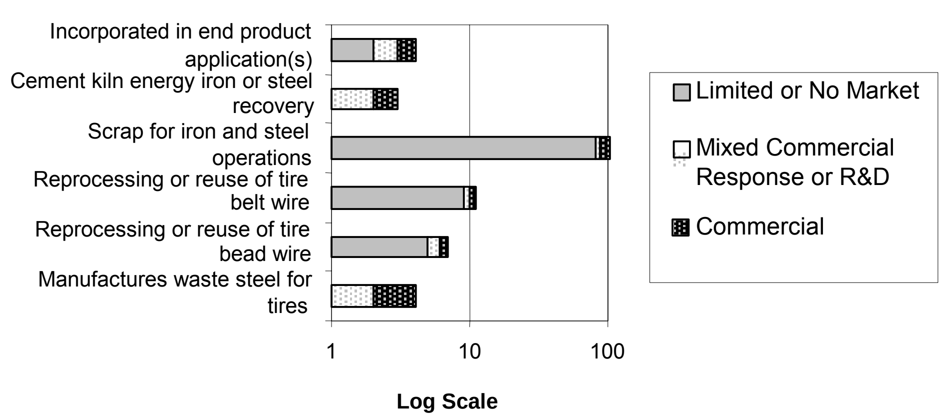
Table 2. Estimated Quantities of Recovered By-Products From Waste Tire Processing in California (2002 and 2007)

	2002	2007
	Tons	
Estimated Potential Diversion		
• Tire-derived steel	18,500	28,500
• Tire-derived fiber	11,000	17,000
Production From Known Sources		
• Steel scrap	Under 2,500	Under 7,500
• TDF fiber	Under 500	Under 500

Steel

The dominant use of tire-derived steel is as scrap steel to manufacture new iron or steel, as illustrated in the Figure A, based on 65 markets responses. Sixty-one percent, or 84 of 134 total responses, indicated that the market for iron and steel mill application is limited or nonexistent.

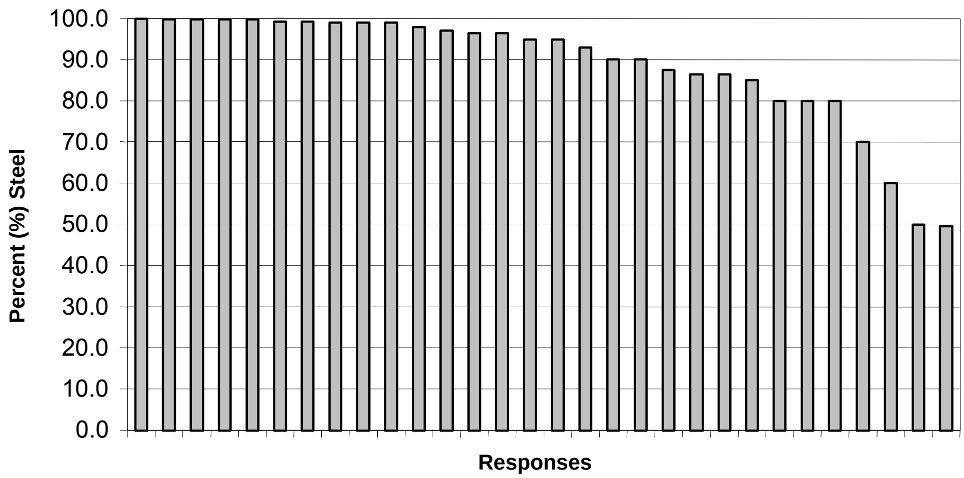
Figure A. Markets View of the Commercial State of Tire-Derived Steel



The largest market for tire-derived steel is still limited or restricted in some localities, according to producers and end users.

In very localized market situations, some very clean steel is being landfilled, while in other situations tire-derived steel with substantial rubber contamination is commercially satisfactory. As shown in Figure B, more than 60 percent of the processor respondents reported product with qualities of 90 percent steel or greater (19 responses of 30); one-third were above 99 percent on steel quality (10 responses of 30).

Figure B. Percent Composition of Tire-Derived Steel



On the other hand, among sellers of tire-derived steel, more than 40 percent were selling steel with contamination of 1 percent or less, while only approximately 11 percent were selling steel with contamination greater than 10 percent, as shown in Table 3.

Table 3. Steel Quality by Commercial Sellers of Tire-Derived Steel

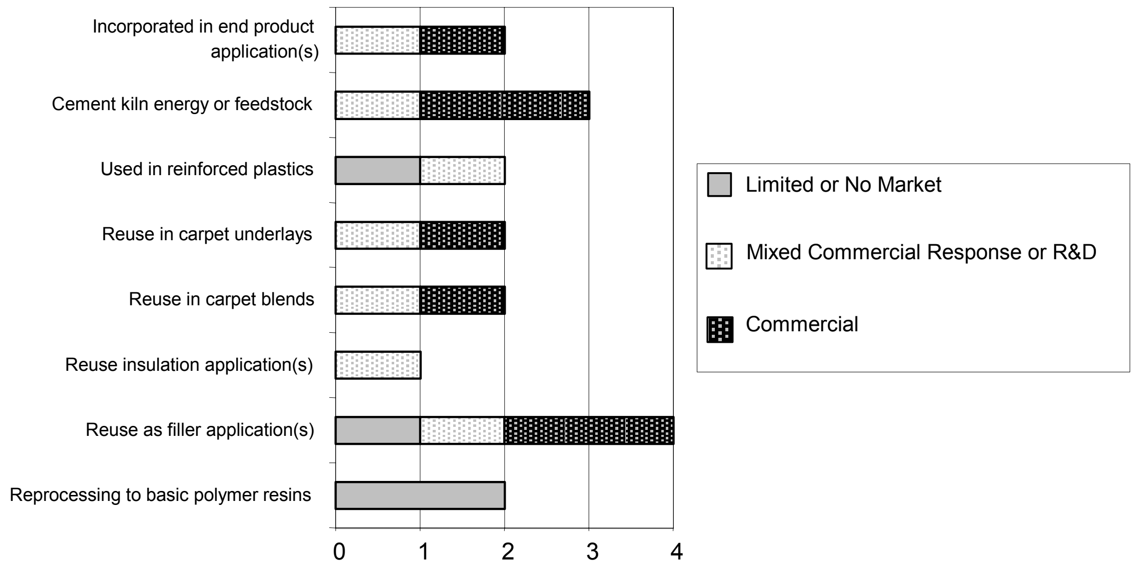
Quality	Percent	Counts
99 percent and over	42.1	8
95 to 98.9 percent	31.6	6
90 to 94.9 percent	15.8	3
Below 90 percent	10.5	2
Totals	**100.0**	**19**

Fiber

Of the more than 300 processors that were contacted, only about 15, or 5 percent, sell fiber TDF for fuel applications.

As shown in the Figure C, the survey responses show limited or no markets for reprocessing fiber back to basic resins. Processing of mixed fiber to resins is not practiced, nor is there any attempt to separate fiber by type. Further, the respondents indicated that there is no research being funded to separate resin types from tire-derived mixed fiber fractions.

Figure C. Processor View of the Commercial State of Tire-Derived Fiber



As shown in the Table 4, the largest market application (21 percent) for tire-derived fiber among all those surveyed consists of its use as fiber TDF. Almost one-quarter of the respondents cited no markets for tire-derived fiber.

Table 4. End Uses Identified for Tire-Derived Fiber

Application	Percent	Counts
Fiber TDF	21.4	15
Rubber	10.0	7
Concrete additive	5.7	4
Carpet	4.3	3
Soil amendment	4.3	3
Proprietary use	4.3	3
Sound deadening	4.3	3
Blanket	2.9	2
Insulation	2.9	2
Target backing	2.9	2
Recycled to plastics	1.4	1
Mulch	1.4	1

Market Overview and Cost Benefit

Market demand for tire-derived steel was found in several regions of North America, but demand for such steel is very limited in California. Reasons for the lack of demand in California include the presence of only one steel mill in California, inadequate steel quality and other properties, lack of knowledge in the marketplace about the potential availability of tire-derived steel, and lack of communication between waste tire processors and potential buyers. Further hampering development of markets for tire-derived steel, capital outlay by facility operators would be required in a number of cases to upgrade tire processing systems with equipment to produce steel to market standards. On the positive side, the study found that if processors invest in equipment to clean steel to high quality, then the probability is that markets could be secured and that the economics would be favorable.

Very little market demand was identified for fiber generated as a consequence of crumb rubber production, either in North America or specifically in California. The chief reasons are substantial contamination of fiber by rubber particles, lack of proven cleaning technology to produce high-quality fiber, mixed composition of the fibers (for example, mixture of polyester, rayon, and nylon fibers), and particle size and shape of fibers. Few fiber users and manufacturers have any experience with tire-derived fibers in particular or more broadly with mixtures of comparable fiber types. The little use of tire-derived fibers that occurs appears to have benefited from opportunistic local-niche markets, markets that have not seen development in California. The study found it difficult to determine feasible uses for tire-derived fiber, acceptable sets of specifications, and market prices. Additionally, readily available performance data are lacking for fiber cleaning equipment.

Recommendations

Given the aforementioned results and status of steel and fiber marketability, a number of recommendations have been formulated with the expressed purpose of improving the recycling of steel and fiber.

Steel

1. Commercially viable processing technology likely exists to produce high-quality tire-derived steel in California. This could circumvent the generally low-quality steel currently produced and the lack of market demand. In practice, tire processors may have to add equipment to further clean and package steel to user specifications. Capital equipment funding assistance would serve to bridge the gap between procurement and installation of equipment and revenue generation as a consequence of steel sales.
2. Currently, data on tire-derived steel characteristics are lacking and not publicly available. This adversely affects the ability of designers, operators, and end users to plan and implement sound, cost-effective tire wire recycling. A need exists for incentive programs to collect and disseminate data on recovered tire wire quality and on the performance of steel cleaning equipment and systems.
3. The Board could assist in improving processor-user communication, which could help develop markets for high-quality tire-derived steel. Funds to sample and market various forms of tire-derived steel in California could substantially improve the dialog among processors, material brokers, and end users. Capital improvement loans or grants could assist processors in the purchase of steel recovery systems or of system components that would generate high-quality steel products.

Fiber

1. The issues and barriers confronting tire-derived fiber recycling in California are many. Most are generated in one form or another by the fine mixed resin composition of recovered tire-derived fiber and its current poor purity. Mixed resin tire-derived fiber is a low-end commodity and has thus far found only isolated, opportunistic market niches. The fuel market (for fiber tire-derived fuel) is insensitive to the mixed resin composition.

This use is very small in California, probably because of the lack of supplies of economic tire-derived fiber and lack of marketing experience in the state. Based on experience elsewhere in North America, concerted efforts to divert tire-derived fiber to fuel markets appear to be warranted.

2. The scarcity of data related to recovered fiber characteristics deters both processors and potential users of the data required to judge applications for tire fiber. Data gathering spurred by Board incentives or facilitation would substantially assist producer/user communication and market development.

3. The entrepreneurial waste fiber and textile companies are some of the best sources of ideas for the use of tire-derived fiber. However, they have yet to be exposed to the material and are therefore handicapped in developing potential applications. Scrap metal dealers offer a similar market development role for tire-derived steel. A sampling program for tire-derived fiber is recommended for consideration, either by individual processors or through regional or national cooperative programs.

4. The commercial development for tire-derived fiber remains in an early stage with no product standards. Single processors may not have resources to push commercial development efforts without incentives or collaborative efforts. Funding by the Board could assist individual processors and/or users and broaden the currently narrow lines of communication between them.

Steel and Fiber

1. Communications among buyers and sellers in the tire-derived by-product marketplace need to be improved. Given their lack of regular commercial dealings, processors face a difficult task in developing new outlets for tire-derived by-products. Compounding this issue is processors' current practice of having waste haulers remove and resell materials—a practice that does not directly develop the processors' markets. Processors should thus consider assuming a greater role in the sale of steel and fiber.

2. Market success is tied to providing a product that meets the needs of customers. Having flexibility in processes to tailor the characteristics of tire-derived steel and fiber is vital to market development with these materials. Processors generally lack engineering staffs, multiple plants, duplicate equipment lines, and other forms of processing flexibility. Their limited resources make it difficult to (a) identify customers and their needs and (b) adjust steel and fiber quality to meet those needs.

   Many processors contacted during the study said that they could not justify the effort, resources, and investment required to pursue an uncertain market. Thus, market development for these by-products will progress at a much slower pace than it might if the Board facilitated market development for steel and fiber. It is recommended that the Board foster and facilitate communication between tire processors and potential markets. This process should include monitoring development of standards, and facilitating development of by-product specifications, product specifications, or both by organizations that set consensus standards, such as the Institute of Scrap Recycling Industries, Inc. (ISRI) and the American Society for Testing and Materials (ASTM).

3. A modest level of incentives or program efforts could probably stimulate substantial recycling of tire-derived steel. A successful development program to substantially increase recycling of tire-derived fiber would likely require a long-term commitment and a multi-faceted approach due to the number and types of barriers involved.

Chapter 1. Introduction

The management of waste tires is a critical issue in the state of California. The California Integrated Waste Management Board (CIWMB) estimates that 33.3 million waste tires were generated in California in 2001. Approximately 75 percent of the generation is diverted; consequently, an estimated 25 percent of tire generation is disposed (*Waste Tire Management Program: 2001 Staff Report* 2003, p. 8). The primary, if not exclusive, motivation and economic driver for diverted tires is the value of recovered rubber. A substantial portion of the waste tires that are generated (about 30 percent) are processed for crumb rubber recovery. During the processing of the tires and recovery of crumb rubber, two by-product streams are generated in significant quantities due to some specific types of materials used in tire construction, namely steel and fiber. Unfortunately, in California these by-product streams are often disposed of. The consequences are an adverse effect on the profitability of tire processing and obstruction of achieving higher recycling levels for waste tires. The CIWMB identified this negative impact during preparation of its *Five-Year Plan for the Waste Tire Recycling Management Program (Fiscal Years 01/02–05/06)*. As a result of the Board's findings, it subsequently commissioned CalRecovery to perform a market analysis of the steel and fiber by-products, with the expectation that the findings and recommendations of the study would ultimately lead to greater recycling of waste tire materials in California.

The overall study is expansive in coverage. One of the reasons is that issues related to recycling of tire-derived steel and fiber have not been exposed to long-term, serious, comprehensive investigation. These by-products have been given due attention only recently as resources available for manufacturing uses. Consequently, a substantial effort was exerted to acquire information from around the world related to recycling of tire-derived steel and fiber.

The overall performance of the study was composed of data collection, data analysis, compilation of results, and formulation of recommendations. The key tasks supporting the study consisted of a literature search to acquire basic information relevant to recycling of the steel and fiber by-products; a survey of tire processors, the tire industry, and markets to collect relevant data; an analysis of supply and demand; an analysis of barriers to recycling; and a cost-benefit analysis.

The study found a significant number of cases of successful recycling of tire-derived steel, although not prevalent in California. However, there appears to be substantial promise for increased recycling of tire-derived steel within the state. On the other hand, the recycling of tire-derived fiber is in its infancy everywhere, and is essentially non-existent in California. Furthermore, a number of confounding factors affect the recyclability of tire-derived fiber. The following chapters of this report provide details surrounding the status of each material, the impacts they have on waste tire processing economics, and suggested means of stimulating recycling of these materials.

Literature Search

The initial task of the study consisted of a comprehensive literature search to establish background information to assist in the performance of the subsequent tasks.

Methodology

The literature search consisted of Internet and library searches. Since this task was primarily one of searching the literature. Therefore, contacts with other potential sources of information (such as university researchers) were limited to those that the study team believed would supplement the information found in the literature, or to those that could provide clarification of information if deemed necessary. A contact list was also prepared based on the findings of the literature search. These contact resources were contacted during subsequent tasks (for example, the survey task, Task 2) in order to collect in-depth information and data. The extent of the literature search was international, but limited to the review and interpretation of information that was available primarily in the English and German languages, since these were the language capabilities of the study team. CalRecovery searched literature databases that contain published research from journals published around the world, journals that publish research from researchers around the world, or both.

The general process of the literature search consisted of searching publications, literature databases, and Web sites. The study team initially searched sources for the period of 1992 to 2002, but quickly found that the vast majority of research and development related to steel and fiber recovery from waste tires, limited as it is, has been performed since about 1997. Consequently, the study team concentrated on following up on any suspected leads of relevant information revealed by a literature source to the extent that additional information might be worthwhile to the study. The search included reviews of abstracts, as well as of full papers and articles. Sources searched included documents such as peer-reviewed journals, trade journals of the tire and tire recycling industries, waste management publications, materials recycling publications, and industry newsletters.

Publications and Internet sites that were searched during Task 1 are listed in Appendix A.

In addition to searching the publications and Web sites listed in Appendix A, the study team placed special emphasis on finding relevant information in the international arena, especially in Europe (European countries are under substantial legislative pressure to divert tire materials from landfill disposal, commencing in 2003, as discussed in more detail later). Various publications, news articles, Web sites, and databases were consulted for abstracts, full manuscripts/articles, and other forms of relevant information and for additional sources of information to consult. Some of the resources reviewed included those listed in the last section of Appendix A.

During the search of the literature, CalRecovery sought to identify waste tire processors; recyclers of tire-derived fiber, steel, or both; characteristics of current waste tires; vehicle and tire industry trends for the future (including the characteristics being touted for new tires in the future); marketing problems and solutions; and relevant experts in the field.

Results of Literature Review

As a broad generalization, the recycling and reuse of tire-derived fiber and steel appears limited based on the results of the literature search. The reasons appear to include the current status of technologies required to clean the fiber and steel to an acceptable quality for the marketplace, lack of market demand for the current quality of these two materials, and economics. Also, there is a dearth of information available on the characteristics of tire-derived fiber and steel. The current situation may change, however, due to the performance of more studies such as this one commissioned by CIWMB and industry initiatives, and in response to current and future environmental policies and regulations. For example, research on uses and recycling of non-rubber, non-polymeric components of waste tires has been stimulated in the United Kingdom as a result of the European Union (EU) landfill directive to ban the disposal of tires in landfills by 2003 and of by-products of tires by 2006.

The results of the literature search are discussed below under the headings of “Tire Construction and Composition,” “Fiber and Steel Components of Waste Tires,” and “Market- Related Issues.”

Tire Construction and Composition

The general materials of construction of motor vehicle tires include natural rubber; synthetic rubber compounds (for example, polybutadiene); polymeric fiber, fabric, and textiles; and fillers, as shown below. (When discussing tire construction, the term "rubber," often refers to natural or to synthetic rubber.) (Rubber Manufacturers Association):

- Synthetic rubber.
- Natural rubber.
- Sulfur and sulfur compounds.
- Silica.
- Phenolic resin.
- Oil: aromatice, naphthenic, and paraffinic.
- Fabric: polyester, nylon, etc.
- Pigments: zinc oxide, titanium dioxide.
- Carbon black.
- Inert materials.
- Steel wire.

Carbon black is an example of a filler material. Other chemical constituents used in tire manufacture include silica and styrene, which are incorporated into the structure of the synthetic rubber compound (Sumner, Engehausen, Trimbach, 2001). The materials and percentages used in tires is primarily a function of the type of vehicle and use, and the design preferences and proprietary formulas of the tire manufacturers. While the composition of tires varies substantially based upon the type of vehicle (for example, commercial truck or passenger car) and severity of use, "typical" compositions are shown in Table 5. Some of the factors that enter into the design and construction of vehicle tires are listed in Table 6.

Table 5. Typical Compositions and Gross Weights of Tires

Material	Composition (weight percent)	
	Passenger	Truck
Natural rubber	14	27
Synthetic rubber	27	14
Carbon black	28	28
Steel	14 to 15	14 to 15
Fabric, fillers, accelerators, anti-ozonants, etc.	16 to 17	16 to 17
	Average Weight (pounds)	
New tire	25	120
Waste tire	20	100

Source: Rubber Manufacturers Association**:**
https://www.rma.org/scrap_tires/scrap_tire_markets/scrap_tire_characteristics/..

Table 6. Some Factors that Govern the Design, Construction, and Composition of Vehicle Tires

General Category	Factor
Economics	• Purchase price • Wear • Product life • Rolling resistance • Retreadability (especially for truck tires and Europe)
Ride	• Vibration • Uniformity • Interior noise • Comfort • Absorption of road irregularities
Safety	• High-speed durability • Puncture resistance • Air retention • Aging stability • Maximum driving safety under various weather conditions (dry, wet, winter)
Environmental	• Noise emissions • Use of materials (production) • Recycling • Retreadability (especially for truck tires and PC tires in Europe)

Source: Bakuniec, 2000, p. 9.

The construction of a tire is relevant to the recycling of tire-derived materials, because a tire is composed of an integrated mixture of materials using thermal and adhesive processes to forge a high-quality tire product. Recovery of marketable materials from tires therefore requires overcoming all of the aspects of integration that make a tire premium consumer product.

An illustration of the construction of a typical tire is shown in Figure D. Among others, a Web site of Continental USA (Continental Tire North America) provides a description of the basic design and manufacturing practices of vehicle tire manufacturers. The basic raw materials for tire construction are natural and synthetic rubber. These materials are processed with carbon black, sulfur, and solvents to form the long, flat bands of rubber that serve as the basic building block of a tire. Several operations are required to manufacture a tire from the rubber and other components, for example, steel. Tread rubber is fabricated using an extrusion process. Sidewalls for the tire are also formed through extrusion. The ply is manufactured from both rubber and fabric. For a steel-belted tire, fine steel wire and rubber are molded into wide, flat sheets. The inner liner of a tire is an impermeable layer of rubber inside the tire that is designed to create an airtight chamber after the tire is mounted on the wheel of the vehicle. The bead is composed of steel wire and rubber and its purposes are to anchor the fabric plies to the tire and to form the required airtight seal with the rim of the vehicle rim. The six major components of the tire (tread, ply, belts, sidewalls, liner, and beads) are formed into a tire using special equipment, heat, pressure, and curing.

Fiber and Steel Components of Waste Tires

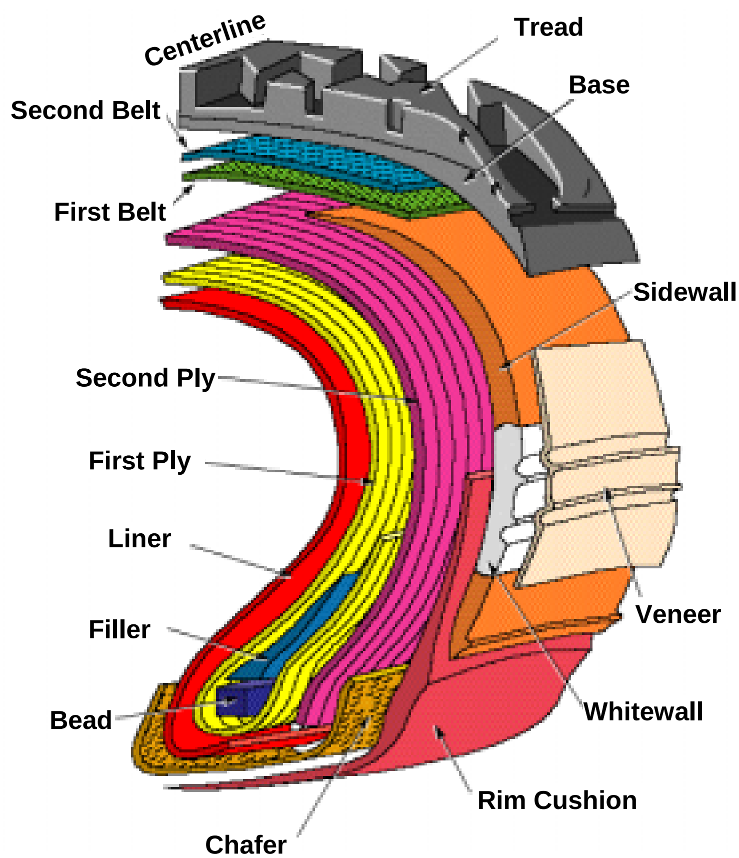
The general function of the textile fiber in tires is to assist in the provision of stable performance of the motor vehicle over the design operating conditions. There are a number of design and operating categories for a vehicle tire, for example, high performance is one category. The composition of fiber has evolved generally from rayon, nylon 6, to nylon 6,6 for medium performance tires. Polyester terephthlate (PET), polyethylene naphthalate (PEN), and aramid (short form of aromatic polyamide) have been introduced as the fiber components for high performance tires, and they are also used in commercial truck tires (Fritsch, 2002; Fritsch, 1999; Murphy, 2001; , Jelsma, 2000). Murphy describes some of the properties (for example, dimensional stability, elastic modulus, and melting temperature) of various fiber materials in Murphy, 2001. An historical perspective of fiber (textile) used in tire construction (and, therefore, potentially recoverable from processing waste tires) is given in Tables 7 through 9.

Table 7. Basic Fiber Construction of Passenger Car Tires Until Adoption of Radial Tires

Historical Time Period	Technology Issue	Type of Tire	Type of Fiber
The first car	Wheel with cushion ring	Solid tire	None
Early mass-produced cars	Rigid axles with pneumatic tires	Cross ply	Cotton
Later mass-produced cars	More sophisticated suspension	Improved cross ply	Rayon
Europe: improved road handling, better fuel economy, fewer flats	More sophisticated suspensions on basis of radial tire	Radial	Steel cord and rayon
United States: emphasis on smooth ride and silence	Power, size, separate chassis, large cross-ply tires	Cross ply	Rayon → nylon → polyester (arrows represent progression of use)
United States: improved handling and ride	Front-wheel drive, downsizing, suspension	Radial	Steel cord and polyester

Source: Jelsma, 2000.

Figure D. Example of Components of a Typical Radial Tire



Source: The Cooper Tire & Rubber Company, 2003
(www.coopertire.com/us/en/information/info-construction.asp)

Table 8. Basic Fiber Construction of Truck Tires Prior to Advent of Radial Tires

Historical Time Period	Technology Issue	Type of Tire	Type of Fiber
Derived from development of first passenger car tires	Wheel with cushion ring	Solid	None
Small truck, low speed	Low axle load	Cross ply	Cotton
Medium truck	Higher axle load, higher speed	Cross ply	Rayon (H.W. Steelcord)
Europe			
Heavy truck	High axle load, adequate suspension	Radial	All steel (steel rayon)
Large heavy truck	Articulated vehicles	Super single	All steel (steel rayon)
Light truck	Adequate suspension	Radial	All steel (steel rayon)
United States			
1 Heavy truck	18-wheeler	Cross ply	Nylon
2 Heavy truck	18-wheeler	Radial	All steel

Historical Time Period	Technology Issue	Type of Tire	Type of Fiber
1 Light truck	Adequate suspension	Cross ply	Nylon/polyester
2 Light truck	Adequate suspension	Radial	Steel and polyester

Source: Jelsma, 2000.

Table 9. Advancement in Fiber Construction Since Industrywide Adoption of Radial Tires

Historical Time Period	Technology Issue	Type of Tire	Type of Fiber
Car			
High speed	Aerodynamics, suspensions, engines	High-speed radial (low aspect)	Belt: steel and aramid, steel and nylon Carcass: rayon (side wall inserts of textiles)
Fuel economy	Engine efficiency, aerodynamics, rolling resistance	"Ultra light weight"	Based on aramid belt
Stable driving sensation	Reduction flat spotting	Material choice	Aramid i.s.o. nylon cap ply
Truck			
Segmentation market/types	Adaption wheel diameter	Low aspect	Compact steelcord, nylon monofil protector, nylon chafers
New light truck categories	Improved suspension; power engines	Improved tires	Polyester carcass, nylon cap ply
Motorcycle			
Racing → Leisure	Engines, suspension, wheels	Cross ply and breaker Radial	Aramid Aramid
Airplane			
Shorter downtime, fewer tire overhauls (civil), lower mass (military)	Reducing heat buildup	Radial	Civil: nylon. Military: aramid
Agriculture			
Highest traction, highest flotation	Optimization contact with ground surface	Radial	(Steel) rayon, polyester, nylon, aramid

Source: Jelsma, 2000.

The steel used in tires has two distinct uses, as steel belting (such as that underlying the tread near the outer diameter of the tire) in some tires, and as the circular metal component (bead) that is encased in rubber at the inner diameter of the tire and assists in sealing the inner diameter against the rim of the vehicle wheel. According to the Rubber Manufacturers Association, a typical passenger car tire contains about 2½ pounds of steel (Rubber Manufacturers Association).

Goodyear indicates that there are 2 pounds total of steel in the most popular passenger car tire (that is, P195/75R14), composed of 1 pound of steel each in the belting and the bead (Goodyear Tire and Rubber Company, 2001).

The composition and properties of the steel in the bead conforms to AISI 1070 or better. As an example, one European manufacturer of steel tire cord (Bekaert) produces normal and high-tensile strength grades of steel cord, having, respectively, carbon contents of 0.725 and 0.825 percent, manganese contents of 0.525 percent, silicon contents of 0.23 and 0.21 percent, sulfur contents of 0.01 and 0.006 percent, phosphorus contents of 0.008 percent, and trace concentrations of copper, chromium, and nickel (Bekaert Group, 2003). According to references (Snyder, 1998; Bakuniec, 2000; CORDIS, 2002), the steel in the bead and belt wire is coated with copper, bronze, or brass. Among other reasons, steel coatings are used to protect the parent steel from corrosion and to promote adhesion of steel cord to the tread. The properties of steel used in tires are subject to research and modification. For example, one research project involved the evaluation of new coatings for cord steel used in tires, including those composed of zinc cobalt, nickel cobalt, or both (CORDIS, 2002).

Market-Related Issues

As a consequence of the literature search, seventeen processing facilities were identified that specifically recover fiber, steel, or both as a by-product of processing waste tires for rubber recovery. A summary of these facilities and key information for certain criteria or topics is given in Table 10. A standard format was developed to compile and report results of the literature search for each of the facilities listed in Table 10. In a number of cases, only certain information was available from the literature. A few of the facilities listed in Table 10 recover the steel rim from forklift tires, as opposed to steel belt or bead steel. Additionally, CalRecovery found several types of technologies that are designed to recover fiber and/or steel. The technologies are listed in Table 11. In addition to the facilities and technologies listed in Tables 10 and 11, a complete listing is given in Appendix B of all waste tire processing facilities and technologies that were identified during the search for those recovering/marketing fiber and steel (but for which recovery/marketing was doubtful or not indicated) and for which some processing information was available.

Table 10. Facilities Identified in the Literature Search as Recovering Fiber, Steel, or Both as By-Products of Processing Waste Tires

Facility Name/Location	American Tire Recyclers, Jacksonville, Fla.
Process/Technology	Uses devulcanizing agent De-Link (made by STI-K, a Malaysian-based company with an office in Wash.) to break sulfur bonds and return rubber to virgin state. Steel is removed magnetically after granulation and fiber is screened for sale.
Capacity	1,000,000 tires/yr
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Crumb rubber, steel, fiber
Uses for Materials	
Contact	Tiffany Hughes, Vice President of Marketing, Jacksonville, Fla.
Source/Citation	Phillips, Mark, "The Trouble With Tires," *Recycling Today*, March 1998, pp. 78–84, 89–92, 96–100.
Facility Name/Location	Bon Terra Systems, Inc., Richmond, Va.
Process/Technology	
Capacity	
Operational Status (year)	
Feedstock	Tires
Materials Recovered	
Uses for Materials	Steel bead wire
Contact	(804) 330-0833
Source/Citation	"Tire and Rubber Recycling Exhibitors, ITRA World Tire and Transportation Services Conference & Exhibition," *Scrap Tire News*, Vol. 12, No. 4, April 1998, p.16.
Facility Name/Location	Broward County, Fla. Waste Tire Removal Plants (2 plants in county)
Process/Technology	De-rimmer operated by inmates at county jail to reclaim steel from rims
Capacity	
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Steel
Uses for Materials	
Contact	Doug Drennen, Broward County, Fla. contracts/grants administrator
Source/Citation	Pedersen, Marialyce, "Scrap Tire Recycling: Turning the Corner of Success," *MSW Management*, January/February 1995, pp. 44–51.
Facility Name/Location	D&L Rubber Works, Ill.
Process/Technology	
Capacity	
Operational Status (year)	

Feedstock	Tires
Materials Recovered	Steel
Uses for Materials	
Contact	
Source/Citation	"Scrap Tire Chips as Playground Surface," *Public Works*, March 1996, p. 65.
Facility Name/Location	Davis Street Transfer Station, San Leandro, Calif.
Process/Technology	Uses patented machinery (Link system) to "shave" the steel off the rubber instead of cutting it. Facility also makes 3/4" crumb.
Capacity	500 tons/mo
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Steel, crumb rubber
Uses for Materials	
Contact	Tom Padia, source reduction and recycling director for the Alameda Board. Run by Waste Management of Alameda Cty and Bay Area Tire Recycling (created by B&W Environmental Solutions of SF). B&W patented the machinery.
Source/Citation	Farrell, Molly, "Recycling Wood and Tires at a Transfer Station," *BioCycle*, April 1998, pp. 77–79.
Facility Name/Location	ECO2 Inc, Hawthorne, Fla.
Process/Technology	Pyrolysis research
Capacity	
Operational Status (year)	Prototype pyrolysis plant
Feedstock	Tires
Materials Recovered	Fuel, carbon black, steel
Uses for Materials	
Contact	
Source/Citation	Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18–27.
Facility Name/Location	Emery Recycling Corp, Huntington, Utah
Process/Technology	Pyrolysis: heating of tires in an oxygen-starved environment to produce a fuel-like liquid, carbon char, and steel
Capacity	25 tons/day
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Fuel, carbon black, steel
Uses for Materials	
Contact	
Source/Citation	Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18–27.

Facility Name/Location	FRT Recycling Technologies, Norman, Okla.
Process/Technology	Pyrolysis: heating of tires in an oxygen-starved environment to produce a fuel-like liquid, carbon char, and steel
Capacity	
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Fuel, carbon black, steel
Uses for Materials	
Contact	
Source/Citation	Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18–27.

Facility Name/Location	Illinois Correctional Industries, Ill.
Process/Technology	
Capacity	
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Steel
Uses for Materials	
Contact	
Source/Citation	"Scrap Tire Chips as Playground Surface," *Public Works*, March 1996, p. 65.

Facility Name/Location	Recovery Technologies, Inc., Cambridge, Ont., Canada
Process/Technology	Cryogenic Reclaprocessor system uses liquid nitrogen to freeze the shredded tire particles below the rubber's brittleness temperature and then fractures the frozen particles into rubber granules, steel and fiber.
Capacity	
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Crumb rubber, steel, fiber
Uses for Materials	
Contact	Bev Crowther (519) 740-6801, Ext. 210
Source/Citation	Trojak, Larry, "Tire Processing Equipment: Shredders and Grinders and More…Oh My," *Recycling Today*, July 2000, pp. 22–29.

Facility Name/Location	Solid Tire Recovery, Inc., Toronto, Ont., Canada
Process/Technology	Waste tires from fork lifts converted into "Clean and consistent quality rubber and high-grade steel from the rim" process called "the stripper."
Capacity	
Operational Status (year)	
Feedstock	Tires
Materials Recovered	

Uses for Materials	"High-grade steel"
Contact	Joint venture with Huron Recovery, Inc., Buffalo, N.Y. No contact info given.
Source/Citation	"New Patented Process for Solid Tire Recovery," *Scrap Tire News*, Vol. 13, No. 11, November 1999, p. 4.
Facility Name/Location	Thermal Flux Corporation, Horsham, Pa.
Process/Technology	"Magnetic heat treatment process that cleanly recovers rubber and steel from industrial forklift tires. Both the rubber and the metal base bands are separated whole—making them especially desirable for recycling."
Capacity	
Operational Status (year)	
Feedstock	Tires
Materials Recovered	
Uses for Materials	Rubber and steel from forklift tires. "The metal bands are recycled for use in the manufacture of after-market tires and for scrap metal." Metal rims are sold for $3.00.
Contact	415-F Sargon Way, Horsham, Pa., 19044. 1-800-784-9677. tjadwin@tfcitr.com.
Source/Citation	"Nailing Down a Niche," *Scrap Tire News*, Vol. 12, No. 3, March 1998, pp. 1–4.
Facility Name/Location	Tire Conversion Technologies, Scotia, N.Y.
Process/Technology	"TCT's patented process removes the buffed tread portion of the tire from the sidewalls as one long strip, leaving the steel tread belt encased in a uniform thickness of rubber. The tread belt is flattened...then laminated together (to make planks)."
Capacity	
Operational Status (year)	2002
Feedstock	Steel belted tires
Materials Recovered	Steel belts used to reinforce planks, rather than discarded as waste product
Uses for Materials	Planks are marketed as Dura Board for retaining walls, fences, etc.
Contact	Jerry Coffin, President and CEO
Source/Citation	"Specialty Construction Materials," *Scrap Tire News*, Vol. 16, No. 6, June 2002, pp. 13–14.
Facility Name/Location	Tirenergy Corporation, King of Prussia, Pa.
Process/Technology	"Advanced pyrolysis technology"
Capacity	
Operational Status (year)	
Feedstock	
Materials Recovered	
Uses for Materials	"By-product sales: carbon black, gas, oil, STEEL" (emphasis added)
Contact	(610) 278-5633

Source/Citation	*Scrap Tire News*, August 2002, p. 17.
Facility Name/Location	Tirex Corp, Montreal, Queb., Canada
Process/Technology	Cryogenic system. The frozen treads or sidewalls are disintegrated into coarse rubber powder and the steel wires and fiber strands remain intact. The wire is removed magnetically and then sold. The fiber is segregated by screening.
Capacity	
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Steel, fiber, crumb rubber
Uses for Materials	Steel purchased by scrap dealers; fiber used as reinforcing for manufacturing rubber and plastic products
Contact	3828 St. Patrick Street, Montreal, Queb., Canada H4E 1A4. Terence C. Byrne, chairman and CEO, Montreal. John L. Threshie Jr., President. (514) 933-2518
Source/Citation	Taylor, Brian, "Same Tired Story?" *Recycling Today*, May 1999, pp. 33–42.
Facility Name/Location	United Tire Recycling, California City, Calif.
Process/Technology	Pyrolysis: heating of tires in an oxygen-starved environment to produce a fuel-like liquid, carbon char, and steel
Capacity	200 tons/day
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Fuel, carbon black, steel
Uses for Materials	
Contact	
Source/Citation	Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18–27.
Facility Name/Location	Waste Recovery, Dallas, Tex.
Process/Technology	
Capacity	2,000 tons/mo
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Steel
Uses for Materials	
Contact	
Source/Citation	Powell, Jerry, "The Hottest Trends in Tire Recycling," *Resource Recycling*, December 1996, pp. 14–20.

Table 11. Technologies and Processes Identified in the Literature Search that Recover Fiber, Steel, or Both as a Consequence of Processing Waste Tires

Facility Name/Location	Akron Rubber Machinery International, Akron, Ohio
Process/Technology	"Fiberator" device, "Approximately 90 percent by weight of fiber is removed"
Capacity	
Operational Status (year)	
Feedstock	
Materials Recovered	
Uses for Materials	Fiber-free crumb rubber
Contact	601 E Exchange Street, Akron, Ohio 44306, John or Mark Hausman (330) 253-2800
Source/Citation	"Fiber-free Crumb Rubber," *Scrap Tire News*, Vol. 12, No. 12, December 1998, p. 8.
Facility Name/Location	Bi-Metal Corporation, Ridgefield, Conn.
Process/Technology	"The system processes the 'dirty wire' to liberate rubber and return it to the recycler. Bi-Metal Corp. also offers a marketing service for the 'clean wire' to ensure it will be sold."
Capacity	
Operational Status (year)	2001
Feedstock	
Materials Recovered	Rubber-free steel wire
Uses for Materials	Company claims that it can "ensure it (steel wire) will be sold."
Contact	(203) 431-4140, mark@bi-metalrecycling.com
Source/Citation	"What's New in Nashville…," *Scrap Tire News*, Vol. 15, No.4, April 2001, p. 19.
Facility Name/Location	GumTec, Saxony, Germany
Process/Technology	
Capacity	
Operational Status (year)	
Feedstock	
Materials Recovered	
Uses for Materials	Steel and fiber specifically mentioned as products recovered from waste tires by their process
Contact	Ziegelstrasse 1 09661 Tiefenbach, OT Arnsdorf Sachsen (Saxony) Germany. Gerald Schmidt 49-3727-62990
Source/Citation	The Rubber Room (www.rubber.com)
Facility Name/Location	Heever South Africa (Pty) Ltd., South Africa
Process/Technology	"The patented non-pyrolytic process recovers rubber in liquid form from the tires and also recovers the STEEL and FIBER components of the tire" (emphasis added).
Capacity	

Operational Status (year)	
Feedstock	
Materials Recovered	
Uses for Materials	Steel and fiber recovery is emphasised in process description
Contact	27-12-997-1608
Source/Citation	"Liquid Rubber from Scrap Tires," *Scrap Tire News*, Vol. 13, No. 9, September 1999, p. 18.
Facility Name/Location	Tire Cutting & Recycle Equipment
Process/Technology	"De-Bead machine removes the tire bead..leaving the sidewall free of wire. The bead wire can now be recycled."
Capacity	
Operational Status (year)	
Feedstock	
Materials Recovered	
Uses for Materials	Steel bead
Contact	1-800-557-5692
Source/Citation	Tire Cutting & Recycling Equipment (www.webcom.com/tires/homepage.htm)
Facility Name/Location	Titan Technologies, Albuquerque, N. Mex.
Process/Technology	Thermal process
Capacity	10,000 tires/day
Operational Status (year)	
Feedstock	Tires
Materials Recovered	Fuel grade extender oil, steel, carbon black
Uses for Materials	
Contact	
Source/Citation	Taylor, B., "On a Roll," *Recycling Today*, Vol. 37, No. 10, October 1999, pp. 28–36.
Facility Name/Location	Tri-C Manufacturing , West Sacramento Calif.
Process/Technology	New shredder technology
Capacity	
Operational Status (year)	2000
Feedstock	Waste tires, fiber from waste tires
Materials Recovered	Crumb rubber, "fluff"
Uses for Materials	
Contact	3100 W. Capitol Avenue, West Sacramento, Calif., (916) 371-0800; Mark Korte (916) 371-0874
Source/Citation	"STN News Briefs," *Scrap Tire News*, Vol. 14, No. 8, August 2000, p. 20.

Nine markets for tire wire and one for fiber are listed in the 2002 edition of *The Scrap Tire & Rubber Users Directory*; a listing of the markets is given in Table 12.

Table 12. Markets for Tire Wire and Fiber Recycling

Category	Company
Tire wire recycling	Ace Equipment Company 4725 Manufacturing Road Cleveland, OH 44135 Tel: (216) 267-6366 Fax: (216) 267-4361 www.aceovens.cc
	Bi-Metal Corporation 440 Main Street Ridgefield, CT 06877 Tel: 1-800-477-5717, (203) 431-4140 Fax: (203) 438-7619
	Budget Steel, Ltd. 2770 Pleasant Street Victoria, BC V8T 4V3 Canada Tel: (250) 381-5865 Fax: (250) 381-3866 www.budgetsteel.com
	Klein Metals 2156 Camplain Road Somerville, NJ 08876 Tel: (908) 722-2288 Fax: (908) 725-9343
	Newell Recycling of Atlanta, Inc. 1359 Central Avenue East Point, GA 30344 Tel: (404) 766-1621 Fax: (404) 766-1123
	SMI-TX Box 911 Seguin, TX 78156 Tel: (830) 372-8670 Fax: (830) 372-8494
	Summit Resources Group, Inc. 7476 Whitemarsh Way Hudson, OH 44236 Tel: (330) 653-3992 Fax: (330) 653-3993
	TAMCO P.O. Box 325 Rancho Cucamonga, CA 91739 Tel: (909) 899-0660 Fax: (909) 899-1910

Category	Company
	Tube City, Inc. P.O. Box 2000 Glassport, PA 15045 Tel: (412) 678-6141 Fax: (412) 678-2210 www.tubecity.com
Fiber recycling	Day Spring, Inc. 2121 Potomac Place Lawrenceville GA 30043 Tel: (770) 995-9881 Fax: (770) 339-9706

There is a considerable lack of any substantive information related to the properties of recovered fiber and of steel, and to uses and markets for these two types of materials. As a result of the literature search, CalRecovery identified only a handful of facilities that market fiber, steel, or both. In cases where information was found in the literature, details were lacking with respect to composition of the marketed materials, buyer specifications, quantities, etc.

Fiber

Very little information was found in the available literature regarding uses and markets for fiber recovered from waste tires. CalRecovery did identify two research studies (Bignozzi, Saccani, Sandrolini, 2000; Bignozzi, Saccani, Sandrolini, 2001) that report on the recovery and use of "micronized" tire fibers as filler for polymers mortars. The micronized fibers were a mixture composed mainly of polyester, rayon, and nylon fibers. This work is currently at the research and development (R&D) stage. However, the preliminary studies have yielded positive outcomes with regard to using tire fiber as mortar filler material.

Potentially relevant to recycling of textile belting from waste tires, cord-yarns (used in the manufacture of tires) have been studied on a laboratory scale for use as reinforcing material for recycled polypropylene (PP) material (Czvikovszky, Hargitai, 1997). Fibers are of interest as reinforcing because they improve the properties of recycled PP resin over those of conventional, recycled PP material. The research found that modification of the yarn fibers using electron beam technology, along with other treatments, was necessary in order to achieve the desired level of bonding between the fibers and the PP matrix.

While not specifically "materials recovery," CalRecovery identified at least one facility (cement plant) that has a permit to combust tire-derived fiber as a fuel (Ciment St. Laurent, Joliette, Quebec, Canada) (*Scrap Tire & Rubber Users Directory*).

Steel

There is one steel mill (TAMCO), in California (Rancho Cucamonga), that processes tire steel. Although this facility has processed both bead and belting steel in the past, currently the mill has shortened its operating schedule and is accepting only bead steel due to the cost of energy in California (Robinson, 2002).

The purity of recovered tire-derived steel affects the marketability of the material, especially the degree of contamination with rubber. During the literature search, CalRecovery identified a few technologies or strategies the may be relevant to improving recovered tire steel quality.

Thermal processing of waste tires represents one method of recovering steel with little or no rubber contamination. For example, Helzer has conducted research on recovering clean bead steel using a new pyrolytic process, as well as on the effect of using the recovered tire steel in various percentages in the manufacturing of cast iron (Helzer, 1994). The recovered tire steel was found to be an appropriate recycled feedstock for the production of gray iron, but not for ductile products because of a high sulfur content.

Several different types of steel fiber recovered from waste tires were evaluated as concrete-reinforcing materials in research conducted in the United Kingdom (UK) (Pilakoutas, 2001). The research was funded by the Dept. of Trade and Industry in the UK (Dti) and only preliminary results of the R&D are currently available. Several different types of steel fiber fractions were prepared and tested as alternative steel reinforcing in the manufacture of structural concrete. Two methods of preparation were employed for recovery of steel: (1) size reduction (which resulted in a certain percentage of rubber contamination in the steel fraction), and (2) melting away of the rubber and recovery of clean steel. According to the authors, the second method of recovery (that is, melting) produced good quality concrete, and the recovered steel fibers were similar in properties to those of conventional reinforcement steel fibers on the market.

Follow-up contact with Dr. Kypros Pilakoutas and with the Dti established that this tire steel research project has not been completed. Dr. Pilakoutas mentioned that since the publication of the paper, additional work has been done which has resulted in applications for patents. Also, according to Dr. Pilakoutas, currently in the UK, steel fibers from waste tires may be accepted by steel furnaces, if the level of impurities is less than 10 percent (weight basis). Dr. Pilakoutas also mentioned that the recovery and recycling of tire textiles is not currently practiced in the UK.

Market Demand

While the supply of waste tires is substantial, the demand for tire steel and fiber as secondary materials appears to be very limited, based on the lack of detailed information on this subject in the literature. While some markets for tire steel have been identified, the literature has little discussion of marketing problems associated with this type of material. A likely reason is the regional nature of most steel mill markets. Also, up until recently, lack of industry specifications for tire steel has been one substantial reason for lack of demand. A similar situation exists in the case of tire-derived fiber. There is little market history for fiber, and the fiber fraction even if devoid of non-fiber materials is still composed of a mixture of several types of polymeric resins (for example, nylon, polyester, rayon, etc.). In addition, there are no applicable industry specifications. The characteristics of recovered tire fiber are even more heterogeneous than those of tire steel.

Contacts

Contacts developed as a consequence of the literature search are cited among the entries given in Appendix C.

Chapter 2. Survey—Methodology, Results, and Analysis of Results

The second task of the study consisted of a comprehensive survey of industry experts knowledgeable in the recycling of tires, the recovery of tire-derived steel and fiber, the market opportunities for these materials, and barriers to recycling of steel and fiber.

Methodology

The survey reached crumb rubber producers, other waste tire recyclers, and industry trade organizations. It identified experts in the field from California, the United States, and internationally. The survey sought their collective wisdom in order to identify markets and potential markets and to define the issues. It identified barriers to recycling of steel and fiber by-products from waste tire recycling processes, as well as potential solutions.

The mail survey was based on a questionnaire prepared by the study team, reviewed by the CIWMB, and pre-tested by a sampling of stakeholders. Follow-up telephone calls and/or email contacts were conducted in order to increase the response rate. The development of the contacts for the survey started with the results of the Task 1 literature search. Identification of additional contacts came from examination of Internet sites, advice from association sources, and the survey respondents themselves.

Throughout the conduct of the survey, great care was taken to maintain the anonymity of the individual survey responses. The results of individual respondents are grouped and reported in the analysis only in aggregate with those of others and are not cited directly by the names of the businesses.

Survey Development

Three questionnaires were prepared to focus on three different segments of the industry. The first group consisted of crumb rubber producers and all other recycling processors of tires. A second questionnaire was addressed to consumers and participants in the sales channel for steel and fiber from the recycling of tires. A third questionnaire captured the knowledge of producers of tires and of fiber and steel components of passenger and truck tires. Each of the three questionnaire forms is incorporated in Appendix D**.**

The survey forms contained contact information and background on specific operations of the company. Contact information was updated internally as part of the survey process. Respondents were encouraged to pass along the names of other experts on steel and fiber by-products recovery and on market outlets.

The survey forms were prepared to be mindful of the wide scope of the CIWMB study, and took into consideration the need to streamline the form in order to make it practical in the collection of the desired responses. After internal review by the consulting team, each of the three questionnaires were reviewed by the Contract Manager at CIWMB and additional feedback was received by more than a half dozen stakeholders from the three segments of the industry: processors, markets, and producers of tires and tire components.

About 1,100 surveys were mailed to waste tire rubber processors, end users of recycled steel and fiber, and the producers of tires and tire components. Because of the nature of the industry and the press of ongoing business by the companies being surveyed, follow-up telephone calls were necessary in order to generate additional survey response and content.

Identification of Contacts

The literature search yielded a large number of contacts from around the world. The survey supplemented the original contact list from the literature search by identifying other contacts with the potential for knowing either the current and potential uses of steel and fiber recovered by tire recycling or the substitute products and their characteristics. The sources for these additional contacts were directories and online news sources, both domestic and foreign sources (see Appendix A). A number of organizations were also identified during the performance of Task 1 and 2 as being potential sources of experienced industry contacts, of project-related information, or both. Among the organizations contacted are those listed below:

- Rubber Manufacturers Association (RMA)
- Steel Recycling Institute (SRI)
- Institute of Scrap Recycling Industries, Inc. (ISRI)
- Society of Plastics Engineers (SPE)
- Fiber Reinforced Concrete Association (FRCA)
- Secondary Materials and Recycled Textiles Association (SMART)
- American Foundry Society (AFS)
- Textile Fibers and By-Products Association (TFBPA)
- American Fiber Manufacturers Association (AFMA)

The RMA facilitated securing responses to the survey from its affiliated tire manufacturers and provided information relative to tires, tire steel, and tire fiber. The SRI, ISRI, and AFS provided background information and industry contacts relative to the processing or marketing of tire-derived steel, or both. The FRCA, SPE, and SMART facilitated contacts with individuals potentially knowledgeable in processing, recycling, and uses of types of plastic resin or mixtures thereof.

Also, some of the representatives of the above organizations or industry representatives affiliated with the organizations served as peer reviewers of the market surveys prior to mailing them to those on the mailing list.

ISRI invited the study team to participate as an observer during a conference call held in January 2003, with its Task Force on Steel in Scrap Tires. At the time of the call, this task force was in the process of developing standards and promotional literature for tire-derived steel. ISRI currently is the single most important driver for establishing standards for transition to a commercially stronger industry for recovered tire-derived steel. Presently, the marketing of these recycled products is underperforming because of the piecemeal response to market demand. Every supplier has an individual definition of its own supply that can change from delivery to delivery. Other goals of the task force are to educate the scrap markets about waste tire steel, determine the attributes and usefulness of substitute products competing with waste tire materials, and determine the constraints limiting tire-derived steel. As a consequence of the work of the Task Force on Steel in Scrap Tires, ISRI promulgated specifications for tire-derived steel in May 2003 (see Appendix E). Unfortunately, neither ISRI nor any other standards development organization is currently studying specifications for tire-derived fibers.

Response Rate

After the initial mailing, a high response rate was achieved by telephoning and emailing (for firms based outside of North America) each non-respondent to the survey. The follow-up was conducted until a response was received, until it was determined the company could not contribute, the company refused to participate, or the limit of two calls per company was reached. In many instances, further calls, faxes, and mailings were also conducted in order to give companies the opportunity to contribute and provide the best balance of opinion by obtaining the widest possible response.

Before undertaking the survey, it was known that relatively few companies in the industry had an understanding of the tire-derived steel and fiber markets. Unfortunately, the only way to ensure contact with this core group of industry experts was to survey all possible companies in applicable industry categories, as well as those identified by press reporting as potentially knowledgeable. As a result of survey process, the study eliminated from consideration a number of firms that are no longer in business, that have switched product lines away from the interest of the study, refused to participate, or were not sufficiently knowledgeable to offer substantive information relative to tire-derived steel or fiber or the competing substitute products.

Respondent Anonymity

When contacting companies, the team informed the contacts that their responses would be maintained confidentially. In addition, only aggregated results would be reported in order to preserve the anonymity of individual businesses. To ensure internal confidentiality, only a small group of study team members has knowledge of the identities of the respondents. In most internal discussions and correspondence, individual companies are referred to by their assigned code and by industry grouping. The company code is not alphabetical and does not follow any consistent pattern. The code identifies which questionnaire type was received from the respondents, as well as from the company. The coded identifiers are used to group respondents into categories such as processor, customers plus end use markets, and producers. With regard to location sorting, because of multiple plants and headquarter locations, the following rule was applied to assign companies to areas: any firm responding from California is listed in the category “California,” responses from states outside of California are categorized as “rest of the United States,” and any returns from outside the United States are categorized as “international.”

Analysis

The Task 2 survey effort resulted in a broad capturing of data and opinions of many industry participants and experts in steel and fiber recycling from tires and their markets. The results of the survey are reported with the realization that unequal returns for selected information may skew findings in some cases. The results of the survey are described in the following subsections.

Survey Responses

The final count of mailed surveys was 1,104. Some 603 surveys were sent to processors, recyclers, and companies with related activities in tire recycling. Another 441 companies positioned in the markets for using, processing, or trading steel and fiber recovered from tire recycling. A final set of 60 companies that make tires and tire components using fibers and steel were also contacted. After eliminating companies due to wrong numbers, firms out of business, or those that changed their product line, etc., the effective survey population was 913. Of those, 603 were successfully reached, or 66 percent. Just under 20 percent refused to participate, and a similar number participated without being able to contribute substantially. Thus, a core group of about 245 became the sources for the survey results. See the Response Table in Appendix F that further details the responses.

The response rate was affected by the large number of contacts that had no experience with steel and fiber recovery from waste tires or knowledge of their potential markets. In attempting to cover all potential knowledgeable contacts, a great many companies identified as potential contributors of information had difficulty defining substitute products for steel and fiber from waste tires. They also had difficulty describing desired characteristics for success with a potential end use.

Many of the respondents know of recycled steel and fiber from waste tires only by rumor or by a vague understanding of industry. Segregated steel and fiber are by-products of the manufacturing steps to produce crumb rubber. There are relatively few successful and consistent sellers of the by-product fiber or steel.

The lack of industry understanding flows from the difficulty in finding customers with the right combination of needs to match with tire-derived steel and fiber properties in a local market. Because this commercial combination is hard to pinpoint and act upon, many processors find it uneconomical to recover steel and fiber for commercial use. Thus, disposal is the only available option. This inability to sell a substantial portion of production is damaging to the industry, since it undercuts the profitability. See the Major Finding section later in this chapter.

Survey Content

Industry Trends

Tires have been getting larger in size for more than a decade. As the popular vehicles such as sport utility vehicles (SUVs) and light trucks continue to increase their market share, the size of tires and the amount of rubber used for original equipment tires has been growing faster than the number of units produced. Also, the vehicle population is continuing to grow, and with it replacement tire sales of increasingly larger tires on average (reflecting the SUV and light truck penetration). Vehicle growth is estimated at less than 1 percent annually for the next five years, versus a 2 to 3 percent per year growth expected for tire rubber. Producers confirmed that tires have been getting larger. From the survey, producers are not forecasting significant changes in the tire construction or the mix of fiber, steel, and rubber.

The steel and fiber materials used in tires generally vary for passenger vehicle tires and for trucks and by construction use; that is, belt cord or body cord. An estimation of the industry-wide breakdown of steel and fiber used in tire construction is given in Table 13.

Modern Tire Dealer describes the typical radial passenger tire as steel belted (3 pounds) with a polyester body cord (1 pound). Among tires being recycled, polyester is about twice the volume of nylon. Much of nylon’s share of the tire fiber market has been lost to polyester. The bias belt passenger tire makes up less than 1 percent of sales. Truck tires are largely radials as well.

Table 13. Materials of Construction for Body Cord and Belt Cord (percent of tires manufactured)

	Passenger	Truck
Belt Cord		
• Steel	99	99
• Aramid	1	1
• Nylon	tr	tr
• Fiberglass	tr	
Body Cord		
• Steel		37
• Polyester	98	61
• Nylon		2
• Rayon	2	

tr = trace quantities.

Source: “Modern Tire Dealer, 2002 Fact Book Statistics.”

The following table (Table 14) on the relative composition of steel and fiber in tires received confirmation from the survey respondents.

Table 14. Typical Compositions (Weight Percent) and Gross Weights (Pounds) of Tires

Ply	Passenger			Truck		
	Radial		Bias	Radial		Bias
	All Steel	All Fiber		All Steel	All Fiber	
Material	*RMA*[a]	*RMA*[a]	*RMA*[a]	*RMA*[a]	*RMA*[a]	*RMA*[a]
Steel	**10-15%**	3-4%	3-4%	**14-16%**	3-4%	3-4%
Bead wire	3-4%	--	3-4%	3-4%	3-4%	3-4%
Other wire	7-11%	--	--	11-12%	--	--
Fiber	--	4-7%	7%	< 0.5%	4-9%	9%
Average Weight	**RMA**[a]			**RMA**[a]		
New tire	25			120		
Waste tire	20			100		
Tread wear occurs during vehicle use. In disposal, tires typically have higher levels of steel and fiber than those shown above (for example, in the case of all-steel belted radial passenger tires, the steel content would be 13 to 19 percent, as opposed to 10 to 15 percent).						

[a] **Source**: Rubber Manufacturer’s Association, 2002.

Applying the ratios contained in the previous two tables, a consensus-building table (Table 15) was prepared showing relative amounts of steel and fiber per tire.

Table 15. Percent Steel and Fiber in Waste Tires (PTE[a] basis)

Steel	Fiber	Other	Total
18	4	78	100

[a] PTE = Passenger tire equivalent.

When the results of survey respondents are taken as a whole, they indicate strong or steady growth in the availability of waste tires, as shown in Table 16. Later in the analysis, the study examines the perception of distinct types of processors (and therefore, types and levels of processing) with regard to anticipated supply of tires.

Table 16. Anticipated Trend for Tire Supply by Processors

	Increasing	Steady	Decreasing
Percent[a]	40.4	47.4	12.3
Counts	23	27	7

[a] percent of responses.

The design and construction of tires is dynamic. Tire companies respond to consumer preferences for safety, economy, and performance by changing the mix of rubber, steel, and fibers. The tire companies are shifting design and materials of construction based upon cost considerations, availability of materials, and the needs of the automobile industry. The rubber industry and the tire companies in particular are frequently reported as being very secretive about their product design and materials of construction. Thus, most suppliers have difficulty knowing whether any increase or decrease in sales is from a bigger/smaller customer market share, different construction design, or the overall trends in the industry.

Tire recyclers are addressing the tire manufacturing choices of the past. Except in rare situations, processors are not able to select tires for processing with specific fiber or steel types. Thus, unless the bead wire is pulled separately, the recovered steel is a mixture of belt and bead wire of different types and grades of steel. Similarly, the fiber obtained in processing is a mixture of resin types (mainly polyester and nylon, with smaller amounts of rayon, Aramid, and cotton). The commercial value of tire-derived fiber is as a mixed blend of fibers. The value of fiber may be downgraded because it likely has trace to large percentages of steel and rubber particles included in its mixture.

Truck tires are typically retreaded two or more times and will be in service for a longer period of time than passenger tires. As learned from the survey, passenger tires will lose as much as 25 percent of their weight before being discarded. New truck tires average about five times the weight of passenger tires and have a much higher percentage of steel. A recycler that has a greater throughput of truck tires will generate a significantly greater volume of steel than an operator that processes an equivalent number of passenger tires. The survey respondents had about equal weights of truck and passenger tires, meaning many more passenger tires were processed.

From the survey, some automobile companies and their suppliers have a goal of as much as 5 to 10 percent recycled rubber. However, this objective does not translate to tire fiber or steel. Tire companies and their suppliers of steel and fiber are not working to improve the recyclability.

Their research and design goals in fact sometimes are counter to ease of recycling, for example, seeking greater adhesion between the fiber and/or steel and rubber. Thus, the tire wire will have a coating of brass or bronze, and fibers are also surface-treated to improve adhesion. In some markets, the constituents of the coatings on steel are attractive. But most scrap steel dealers and mills see the coating as undesirable or as a complication requiring an adjustment to the melt blend in order to achieve the right chemistry and specification for their final end products.

The industrial waste and surplus tire wire and fiber from tire companies or their respective manufacturers (home scrap) is readily recycled. The tire wire value is low ($20 to $25/ton) and can be negative, especially when the total cost of preparing the waste for sale is considered. The goal is to sell steel rather than incur the cost of disposal. Tire-derived steel has major disadvantages over manufacturing waste, principally adhered rubber. See the Barriers and Issues section of Major Findings.

Scrap single resin fibers (home scrap) can also be recycled or reused. This scrap fiber will command a portion of the selling price for new fiber. In contrast, recycled fiber from tires is a mixture of fibers that can be sold only to mixed commodity markets or for its inherent energy value. The value of mixed fiber depends on the alternative materials that it competes against in conventional markets, such as coal in the energy market or fiber used in specialty product markets (for example, sound-deadening material). Fiber companies are not considering converting recycled tire-derived fiber back to polymer resins even at the research level, nor are there any current government-funded programs promoting the recovery of individual monomers from mixed tire-derived fiber feedstocks.

The tire processing industry has low barriers to entry. Ironically, many processors told the study team that they find higher margins by leaving steel and fiber incorporated in tire chips for applications such as TDF, or for civil engineering and landfill cover markets. The tire is sized-reduced to approximately 2-inch pieces. Shredding operations[1] have lower capital and operation costs than crumb rubber operations that break down the rubber into much finer-sized particles with processes such as cryogenic and ambient grinding. The amount of residual fiber or steel produced in coarse shredding operations is considerably less than that produced during recovery of crumb rubber. The fiber and steel can frequently be sold off with the rubber. Recyclers who process only a coarse shred can “sell” steel and fiber intact with the tire chip.

Responses by Industry

Processors: Some processors responded that they lowered margins when making cleaner tire-derived steel or fiber. The fine grinding processes generate steel and fiber that, if not sold, must be disposed. Some processors that have already made the necessary investment for making crumb rubber and cleaner steel and fiber have idled their equipment in favor of making the coarser products.

The industry has many regional faces. For example, a creative processor may find outlets for both steel and fiber in one section of the country that may not exist elsewhere. Processors in some geographical areas may simply be too far from market opportunities for fiber or steel, regardless of the quality of products produced.

Almost 80 percent of processors—the principal group surveyed—are companies engaged in tire recycling or the processing of tires. A small number of firms haul or collect tires, and some cut the tire into sections for burial or further processing by others. As shown below, the survey

[1] This report lumps coarse processing of tires under shredding to simplify the discussion (other similar processes are chopping, punching, and sectioning).

captured the opinions of contacts from a variety of related activities. The total core group of processors responding to surveys with useful content is 114, as shown in Table 17.

Table 17. Processor Survey Participants

Category	Percent	Counts
Processors	61.4	70
Recyclers	10.5	12
Processors—not operating	7.0	8
Technology	5.3	6
Tire haulers and resellers	4.4	5
Waste tire rubber products	4.4	5
Rubber processors	3.5	4
Tire wire brokers	1.8	2
Collection points	0.9	1
Steel mills	0.9	1
Totals	**100.0**	**114**

The average operating years for the responding firms is $16^{1}/_{10}$ years ± $3^{7}/_{10}$ years[2] (66 responses). A high percentage of firms is entering, leaving, or not producing because of explosions and fires (hazards of the business).

Figure E shows that most surveyed processors believe that steel and fiber recovery operations are already fully commercialized. The survey also found that new firms and technologies are entering the business and that processing systems are being modified or expanded for a variety of reasons.

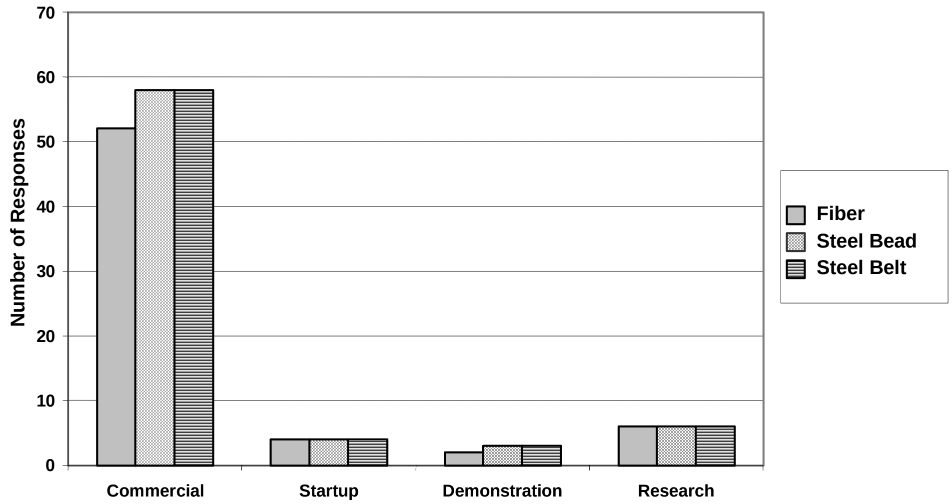
More than one-quarter of the responding firms are making TDF or civil engineering or final rubber products that may be simply leaving steel and fiber intact in their final product. They thus avoid the issue of by-product disposal. Regarding by-product management, some 61 percent of responding processors are disposing of fiber rather recycling it (48 response of 79) and 38 percent of the responders said steel was not being recycled (27 responses of 72).

Figure F shows the wide size range of individual processors. Among responding processors, several reported daily tire throughput capacity in passenger tire equivalents (PTEs) of more than 30,000, while others processed fewer than 20.

The responding companies use a variety of unit operations to recycle tires. Some firms employ multiple operations; for example, shredding first, followed by ambient grinding, or both ambient and cryogenic grinding. As used in this report, shredding operations generate coarse material (that is, on the order of 2-inch product) and ambient and cryogenic grinding processes produce finely sized particles of rubber (for example, 30 mesh). The three principal recycling processes that account for more than 93 percent of reported capacity are coarse shredding and ambient and cryogenic grinding, as shown in Table 18.

2 When displaying an average for a range, values bracketed by a 95 percent confidence level are also shown.

Figure E. Stages of Recovery for Steel and Fiber Operations From Waste Tires



An analysis of the views of processors as a function of their final operational steps shows that firms in the cryogenic and ambient grind categories are optimistic about the future supply of tires. The data are given in Table 19. A high degree of correlation exists between these two processing groups.

Figure F. Share of Reported Daily Volume of Waste Tires

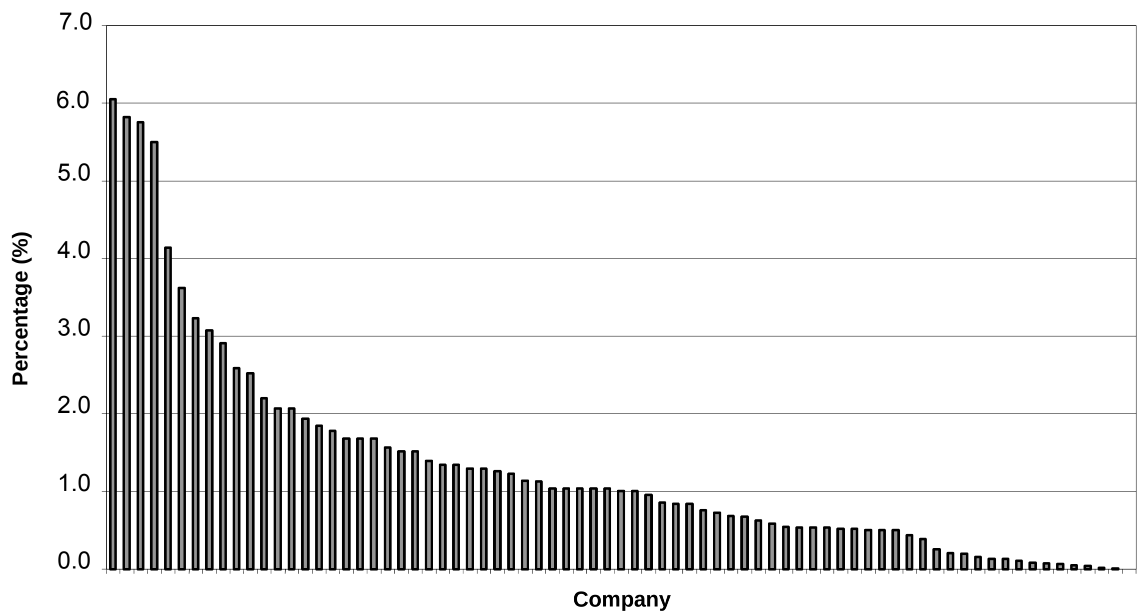


Table 18. Processor Results—Highest Operational Tire Recycling Step

Process Step	Percent	Counts
Grind—cryogenic	13.8	13
Grind—ambient	38.3	36
Shredding—coarse[a]	41.5	39
Sectioning of tires	4.3	4
Grind—wet	1.1	1
Pyrolysis	1.1	1
Totals	**100.0**	**94**

[a] In this report, all processing steps that yield coarse materials that typically do not separate fiber or steel are referred to collectively as shredding. The shredder is a piece of equipment commonly used to make TDF, civil engineering materials, or landfill cover products. A shredder can also be used to prepare materials for other grinding and processing units.

Table 19. Processor View (all geographical areas) of the Tire Supply Outlook
(number of responses)

Tire Supply	Increasing	Steady	Decreasing	Correlation
Grind—cryogenic	4	3	0	0.915
Grind—ambient	8	9	0	0.998
Shredding	6	8	9	-0.633
Totals	**18**	**20**	**9**	
Cryogenic to ambient				0.941
Cryogenic to shredding				-0.891
Ambient to shredding				-0.686
Grind—cryogenic	57	43	0	100
Grind—ambient	47	53	0	100
Shredding	26	35	39	100
Totals	**38**	**43**	**19**	**100**

The market outlook for those companies that process tires for tire-derived products only is broken down in Table 20 by their highest level of operation. In the case of steel, companies categorized as ambient grind or shredding operations have a very similar outlook, as reflected by the correlation shown in the table. Firms using cryogenic processes are bipolar in their responses, being either more positive or more negative. While the sample size is small, the bipolar result may be partly or entirely explained by the fact that cryogenic processors tend to have high economic risk due to highly committed capital and difficulty in finding and maintaining a suitable long-term outlet for steel.

In the case of markets for fiber, the correlation between processors utilizing cryogenic and ambient operations is high. A small percentage of processors in these groupings is displaying some market optimism, but a substantially higher percentage indicates market pessimism, as reflected by the data indicated in Table 20. Processors employing only shredders are somewhat less pessimistic than those that use cryogenic or ambient grind processes, probably because some operations with shredders have the ability to sell fiber into the TDF application by including the separated fiber in to the customer delivery (see Table 20).

Table 20. Processor View (all geographical areas) of the Market Outlook for Recovered Steel and Fiber

	Good	Fair	Poor	No Market	Correlation
	Counts				
Steel					
• Grinding—cryogenic	7	3	3	5	0.492
• Grinding—ambient	13	5	15	11	0.982
• Shredding only	13	10	15	12	0.906
Totals	**33**	**18**	**33**	**28**	
• Cryogenic to ambient					0.322
• Cryogenic to shredding					0.084
• Ambient to shredding					0.964
Fiber					
• Grinding—cryogenic	1	1	0	7	0.895
• Grinding—ambient	1	5	2	15	0.937
• Shredding only	1	2	10	7	0.571
Totals	**3**	**8**	**12**	**29**	
• Cryogenic to ambient					0.964
• Cryogenic to shredding					0.172
• Ambient to shredding					0.258
	Percentages				
Steel					
• Grinding—cryogenic	39	17	17	28	100
• Grinding—ambient	30	11	34	25	100
• Shredding only	26	20	30	24	100
Totals	**29**	**16**	**29**	**25**	**100**
• Cryogenic to ambient					
• Cryogenic to shredding					
• Ambient to shredding					
Fiber					
• Grinding—cryogenic	11	11	0	78	100
• Grinding—ambient	4	22	9	65	100
• Shredding only	5	10	50	35	100
Totals	**6**	**15**	**23**	**56**	**100**

Markets: In addition to seeking data and opinions from processors and recyclers, the survey covered customers and other participants in the consuming sector or distribution channel. The core group responding to the markets questionnaire survey is 105. The markets group provides a buyer perspective for comparison to the selling perspective of processors. The percent breakdown of core group market responders by category is given in Table 21.

Table 21. Markets Survey Participants

Category	Percent	Counts
Cupola furnace	37.1	39
Electric arc furnace	26.7	28
Scrap metal dealer	21.0	22
Waste fiber dealer	4.8	5
Foundry	3.8	4
Consumer	1.9	2
Technology	1.9	2
Recycler	1.0	1
Collection point	1.0	1
Cement plant using fires as fuel	1.0	1
Totals	**100.0**	**105**

While the percentages are different, the markets group reported the process sources for their purchase of fiber or steel in the same order as the responding processors (that is, shredding first, ambient grind second, and cryogenic grind third), as indicated in Table 22.

Table 22. Markets Results—Highest Operational Tire Recycling Step

Process Step	Percent	Counts
Chopping	14.3	3
Shredding	38.1	8
TDF (tire-derived fuel)	14.3	3
Grind—ambient	19.0	4
Grind—cryogenic	14.3	3
Totals	**100.0**	**21**

The source of tire-derived fiber or steel to the end use markets are listed in Table 23. Recyclers or processors bear a large part of the direct marketing responsibility. Scrap metal dealers are instrumental in marketing steel scrap to the foundries, steel mills, and the export markets. Since no waste fiber dealer surveyed handled tire-derived fiber, the burden of marketing fiber apparently rests completely on the processors.

Table 23. Commercial Source of Supply to End Use Markets

Source	Percent	Counts
Directly from tire recycler	48.0	12
Scrap dealer	28.0	7
Captive recycling operations	12.0	3
Distributor, importer, exporter, reseller	4.0	1
Seller of tire wire, bead wire, or tire fabric	4.0	1
Tire hauler	4.0	1
Totals	**100.0**	**25**

Producers: Surveys were also sent to producers of tires and tire components to gain insights on the direction of the markets for tires and steel and fiber tire components. The producers offered yet another set of barriers, issues, and recommendations regarding the recycling of tire-derived steel and fiber. The breakdown of the core group of 25 producers is shown in Table 24.

Table 24. Producer Survey Participants

Category	Percent	Counts
Tire makers	36.0	9
Tire wire producers	16.0	4
Fiber producers	16.0	4
Waste fiber dealers	12.0	3
Tire components	8.0	2
Steel mills	8.0	2
Consumer of waste fibers	4.0	1
Totals	**100.0**	**25**

By-Products

Steel: The two main sources of steel are bead wire and belt wire. The bead is composed of many wraps of thin wire that is used to add structural stability to the tire as well as serving as the mechanism to allow the tire to form a tight leak-proof hold on the wheel rim. The bead can be separated by any of the shredding and grinding operations that recover rubber, as well as by a debeader or puller. About one-quarter of the responses mentioned a debeader (13 responses of 56). (Debeading is also discussed in the Economic Drivers section.) Bead wire is generally lower carbon steel than belt wire and has a thicker wire gauge. Some tire companies use the same grade of steel for both. Chopping into small length and compacting bead wire into blocks is the most saleable steel from tires. However, processed bead wire is a difficult material to package because of its springiness and resistance to compaction or to forming into a bundle.

Belt wire is composed of cords of very thin, high tensile wire that has been wrapped and twisted. This provides stability and strength to the tire tread and sometimes, particularly in trucks, to the body of the tire as well. Ambient grinding can be used to strip out tire belt cord cleanly. Another method of separating tire steel cord is the cryogenic process. This freezes the material and breaks it apart quite cleanly with a hammermill. The belt wire is said to look like steel wool after final processing in a cryogenic operation. Fibers are also said to be separated very cleanly. Clean, recovered steel belt wire may have a high value for some customers because of its high tensile strength.

The technologies used by responding processors to segregate, recover, and package tire-derived steel are broken down in Table 25.

Figure G. Markets View of the Commercial State of Tire-Derived Steel

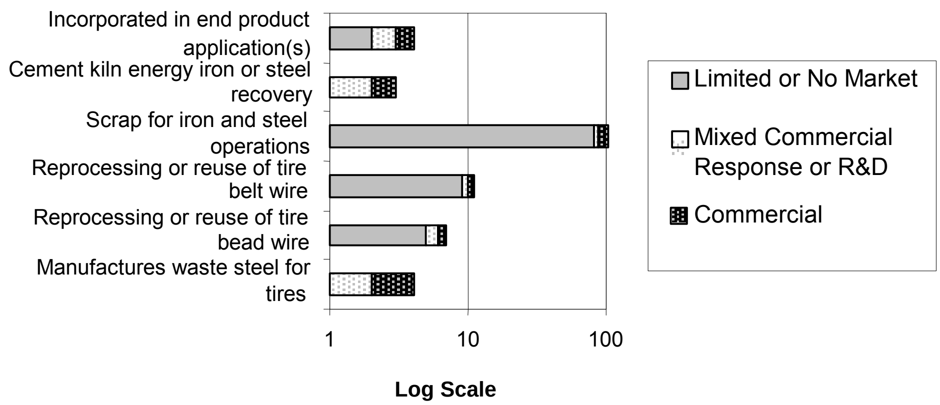


Table 25. Technology to Recover Tire-Derived Steel

Equipment or Operation	Percent	Counts
Belt magnet	34.2	41
Bead magnet	26.7	32
Screens	14.2	17
Debeader	10.8	13
Belt	5.8	7
Gravity	2.5	3
Post-processing	2.5	3
Granulator	1.7	2
Compactor	1.7	2
Totals	**100.0**	**120**

Processing operations generally do not distinguish among types of tire wire (because they do not separate tires by type of body or belt cord steel). Thus, processors generate a mixed steel scrap as a result of cutting or grinding away the rubber from steel. Clean wire is produced by running the process longer or recirculating the wire through the process. The final form of wire is short pieces. Particularly, if a shredder is used, the steel is sliced into shreds, typically under 2 inches.

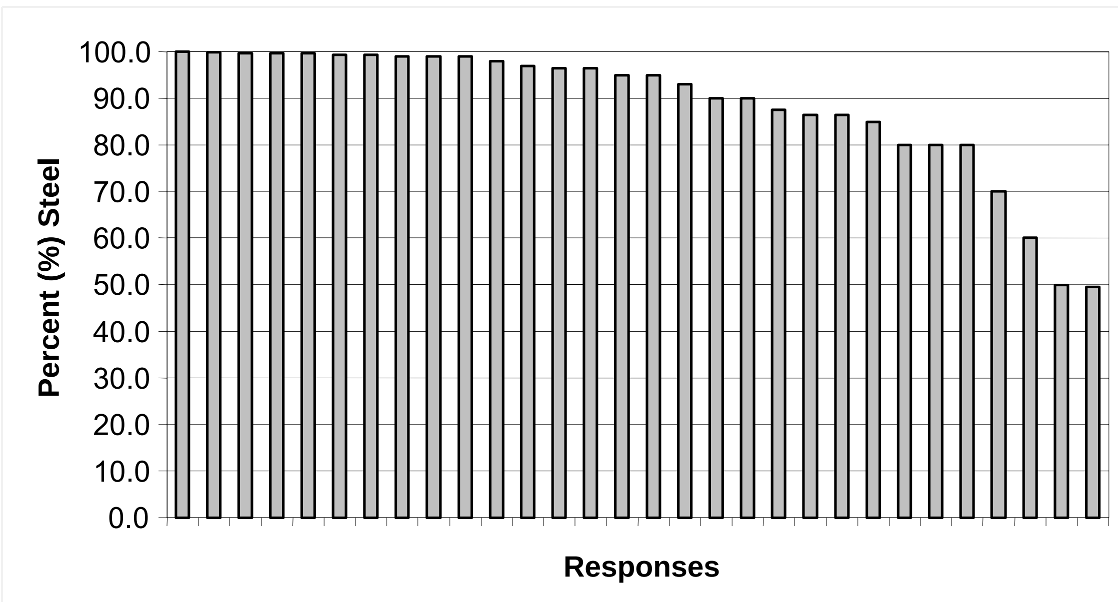
The dominant use of tire-derived steel is remelt to form new iron or steel, as illustrated in Figure G, based on 65 markets responses. Sixty-one percent, or 84 of 134 total responses, indicated that the market for iron and steel mill application is limited or nonexistent. The largest market for tire-derived steel is still limited or restricted in some localities, according to producers and end users.

The manufacturing scrap (or home scrap) is simply remelted and reused by some tire wire producers. According to almost all of the respondents in the survey, waste tire steel is not a candidate for reuse. It cannot meet the scrap specification set by tire wire makers. Rubber and the bronze or brass coatings are singled out as the main limitations to use. However, one processing company with a very clean steel product reported that tire wire is being successfully reused.

According to the survey data, applications for coarse rubber and incorporated steel and fiber are growing. These applications include TDF or tire products made from sections of a tire, such as animal stall separators.

In very localized market situations, some very clean steel is being landfilled, while in other situations tire-derived steel with substantial rubber contamination is commercially satisfactory. As shown in Figure H, more than 60 percent of the processor respondents reported product with qualities of 90 percent steel or greater (19 responses of 30); one-third were above 99 percent on steel quality (10 responses of 30).

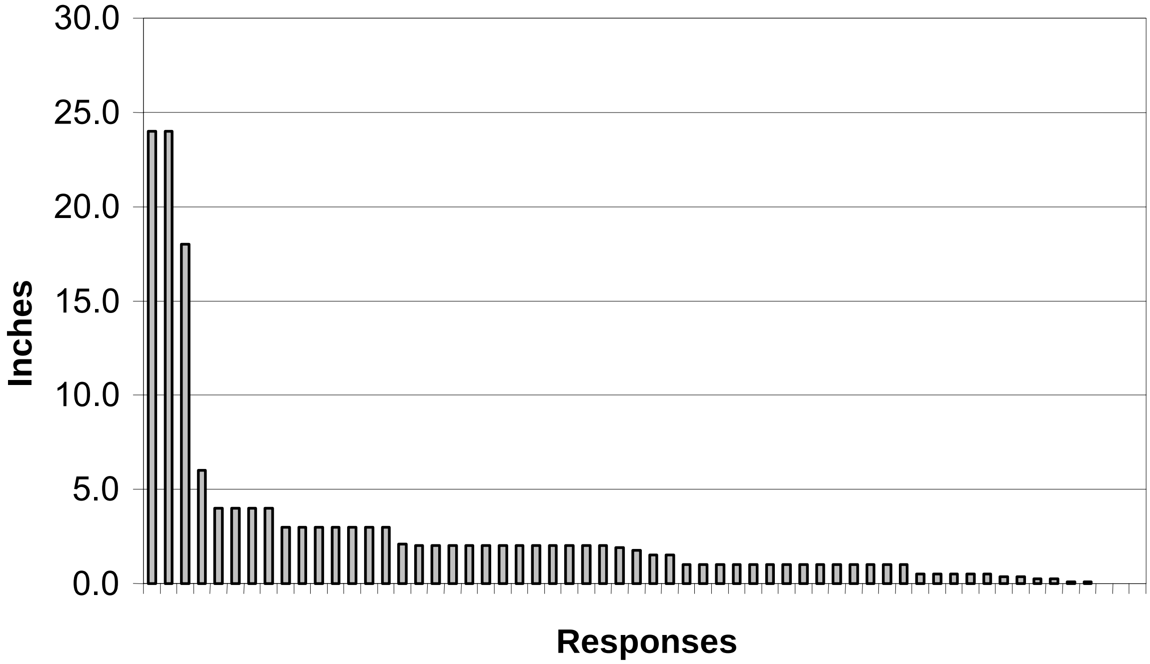
Figure H. Percent Composition of Tire-Derived Steel



On average, the processor survey respondents generate about 3½ pounds of steel per tire (PTE basis). This is a high level of recovery considering availability of steel in passenger tires. By using PTEs to describe the volume of tires processed, the higher truck tire concentration of steel is reflected. A standard steel-belted passenger tire contributes about 2½ to $3^{8}/_{10}$ pounds of steel per tire. The steel in truck tires, when reflected in terms of PTEs, would be in the higher end of the aforementioned range. Operations using shredders as the final processing step tend to generate less than one-quarter of the amount of fiber or steel that ambient or cryogenic grinder processes create. As noted earlier, shredders normally produce coarse size-reduced pieces of rubber, with incorporated fiber, steel, or both as a final product. The amount of steel and fiber produced is much higher in processes aimed at maximum separation of rubber and generation of fine rubber particle sizes.

Responding processors generate steel product up to about 24 inches in length (see Figure I). The longer lengths of steel are characteristic of shredding operations or bead wire processing. The

Figure I. Average Particle Size of Tire-Derived Steel



resulting bulk density can be lower than that of steel product with smaller particle sizes. For example, steel processed to less than or equal to ¼-inch lengths could have a bulk density of 88½ pounds per cubic foot (1 response of 6), while a more typical size averaged 2½ inches ± $1^{2}/_{10}$ inches (30 responses), and might have only a bulk density of 30 pounds per cubic foot (3 of 6). Uncompacted processed steel is substantially less dense than compressed forms.

Bulk density of steel scrap is important for foundries and remelting operations. One reason is that loss of steel occurs as a result of vaporization in electric arc furnaces. The loss carries over into baghouses in cupola furnaces if low bulk density forms of steel are included in the charge. In addition, markets respondents say that they prefer compacted or bundled packaging because the steel is easier to transport on-site and is delivered without losses. This form of packaging reduces danger from falling steel pieces that can puncture tires and jam conveyor belts.

Since rubber contamination can affect the marketability of tire-derived steel, some sellers of tire wire burn off adhered rubber to increase salability of the wire. However, this method of rubber removal may alter the properties of the steel. Companies are seeking improved methods of rubber removal by combustion, chemical, and mechanical means.

Another significant marketing issue is alloy content of the tire steel. Most obvious is the bronze coating on bead wire and brass coating on belt wire. The high tensile belt wire can be made from grades 70 to 80 carbon steel that might contain other metals such as magnesium. Foundries with very tight specifications on selected metals, such as copper (in the tire wire coatings), will not use tire wire.

The market price for steel and the commercial success of processors are not strictly tied to product steel with less than 1, 2, 5, 7, or 10 percent rubber. This observation is based on the survey results as indicated in Table 26. Various levels of contamination less than or equal to 10 percent were deemed by processors to be acceptable to the marketplace. Out of 82 operating processors and tire recyclers, 35 percent (29 companies) appear creditable as suppliers of tire-derived steel. The table below shows that only two companies reported an attached rubber content of more than 10 percent. At this level of contamination or above, the steel is normally being stockpiled or disposed.

Table 26. Steel Quality by Commercial Sellers of Tire-Derived Steel

Quality	Percent	Counts
99 percent and over	42.1	8
95 to 98.9 percent	31.6	6
90 to 94.9 percent	15.8	3
Below 90 percent	10.5	2
Totals	**100.0**	**19**

The scrap market shifts with its business cycle, thereby changing the point of supply and demand balance. Tire-derived steel can be used in periods of peak demand and be cut out as the market encounters slow demand periods. Rubber-contaminated steel has many attributes that scrap market dealers and mills/foundries want to avoid. Consequently, the processor may have to pay markets to take rubber-contaminated steel, or give the material away even though clean (high-quality) scrap steel prices might be $40 to $60 per ton or more.

A representative comparison of market prices as a function of steel content is shown in Table 27. These market price estimates are taken from a variety of sources, such as the processors, new entrants to the industry, and a variety of other firms with close ties to tire-derived steel. These include manufacturers of TDF with contained steel, and technology companies selling equipment or services to processors and recyclers.

The average market price estimate for tire-derived steel from all processors was $\$35^{9}/_{10} \pm \$4^{3}/_{10}$ per ton (46 responses). Market price versus steel quality is plotted in Figure J. From these data, the pricing of tire-derived steel does not correlate well with steel quality; for example, rubber concentration. The scatter of the data suggests that the tire-derived steel market is driven by local conditions. Freight may be a factor. At least a few processors are “selling” tire-derived steel at negative values, while others are getting very modest netbacks so that they can avoid their only other option, disposal.

In spite of the data scatter depicted in Figure J, a simple moving average of the prices tracks in a narrow band within a few dollars of $30 per ton until steel quality reaches 90 percent. For steel quality greater than 90 percent, the slope changes, and the moving average increases to about $50 per ton at 100 percent steel quality.

Estimated prices were also collected from the scrap material dealers and foundry/steel mills. The average of the end users’ estimates for tire-derived steel (a sample size of 6) was only $8.40 ± $15.2 per ton. Four of six estimates assume the tire-derived steel would be given away.

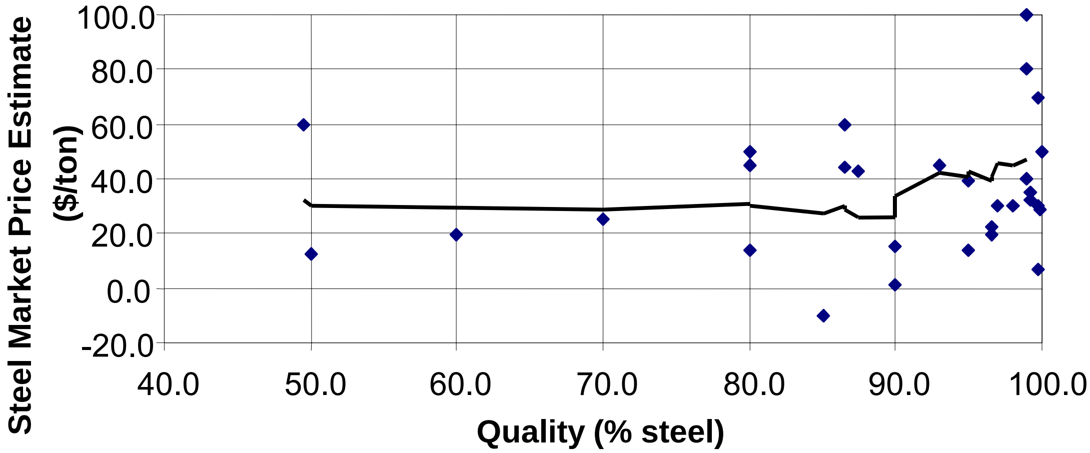
While the price data depicted in Figure J is based on estimates by processors, a more accurate indication of market prices is reflected in the prices reported by those selling tire-derived steel as a steel commodity. The prices are summarized in Table 27 as a function of quality. Clearly, this data shows that selling price is a strong function of degree of cleanliness of the steel. The results also indicate the variability of the data due to such factors as the state of regional supply and demand.

Table 27. Market Price Estimates by Commercial Suppliers of Tire-Derived Steel

Quality	Average Price ($)	95 Percent Confidence Interval	Counts
99 percent and over	42.2	26.2	8
95 to 98.9 percent	23.5	12.9	6
Below 95 percent	20.0	14.2	5

Many markets respondents indicated that tire-derived steel can be easily sold if rubber-free. At least 10 respondent sellers are recovering steel with less than 1 percent attached rubber. Other sellers have heard the message, but the additional expense to generate very low rubber content is not justified. Thus, this latter group attempts to sell steel with 1 to +10 percent content rubber contamination.

Figure J. Estimated Market Price Based on Processor Responses



Distance to market causes many potential deals to net back little or nothing after the freight costs are factored in. The maximum reported shipping distance was more than 400 miles. Break-even conditions are usually less distant. The average shipping distance was $85^{9}/_{10} \pm 33^{1}/_{10}$ miles (29 responses). Transportation costs are profoundly affected by local conditions. For example, circumnavigating a metropolitan area has much different transportation costs than long haul across wide-open country.

Many processors reported that their by-product steel is sold to or taken away by a third-party recycler. In either case, the processor is allowing the recycler to capture any value.

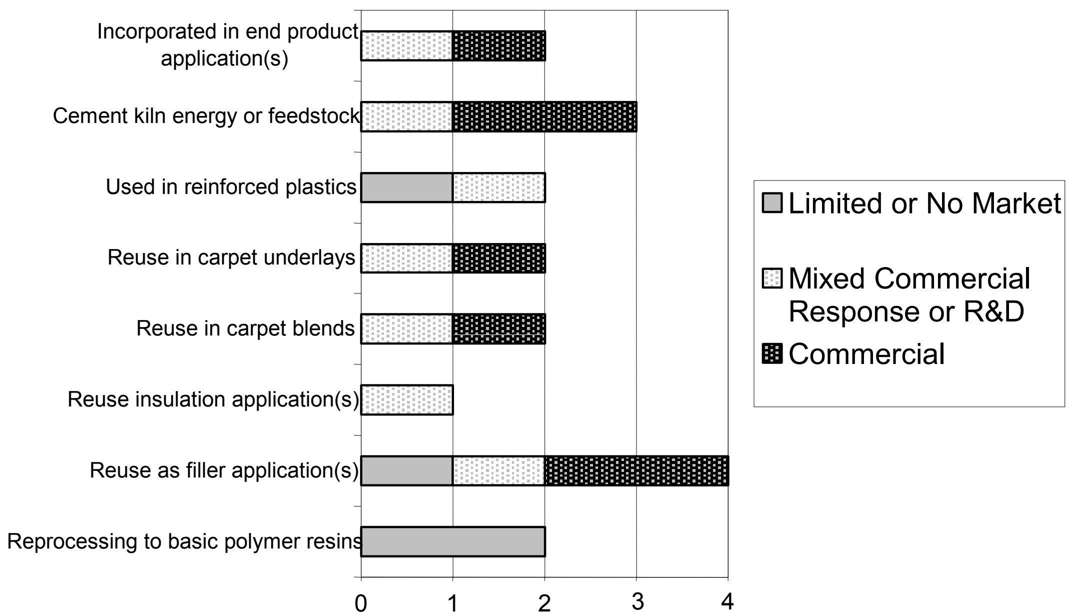
If the tire-derived steel is disposed, the cost of disposal can be high, making negative price selling or long-haul sales better alternatives. The average reported disposal cost among all processors was $32.2 ± $4.5 per ton (38 responses). Processors reported that shipping distance to disposal facilities ranged from several miles to hundreds of miles, with the average distance being $39^{1}/_{10}$ miles $\pm 11^{2}/_{10}$ miles (24 responses).

Fiber

Recovered fiber from waste tires is described by some processors as fibrous "fluff," with the appearance of cotton or dirty cotton. The fiber is normally collected using screening systems, air classification systems, or both. Due to the methods of processing waste tires and of segregating product streams, rubber and steel particles tend to snare themselves in the fiber fraction. Beneficiating the fiber fraction is difficult.

As shown in Figure K, the survey responses show limited or no markets for reprocessing fiber back to basic resins. Processing of mixed fiber to resins is not practiced, nor is there any attempt to separate fiber by type. Further, the respondents indicated that there is no research being funded to separate resin types from tire-derived mixed fiber fractions.

Figure K. Processor View of the Commercial State of Tire-Derived Fiber



Tire-derived fiber has dozens of limited markets and a few substantial ones. Shredding operations making TDF will dispose of any excess fiber as added mass to the TDF. The fiber heating value is in the range of 14,000 to 16,000 Btu per pound, on a dry weight basis. Tire-derived fiber can quickly adsorb moisture. Fiber with high moisture content is valued less than drier fuels. Baling the fiber helps in some cases to reduce the water content. Either in loose or baled form, the fiber can cause problems with existing feeding systems of utilities, or of paper or cement companies. Some processors report fuel users resisted or are likely to resist installing new feed systems for small quantities of low-cost fiber.

Waste fiber dealers are generally not aware of tire-derived fiber and, therefore, are not looking for outlets. The waste fiber and textile scrap business is focused almost exclusively on clean, single-resin, long-length fiber for reuse in textile applications. In contrast, tire fibers typically are composed of a mix of resins. They are dirty, short in length, and crimped (that is, bent). Nevertheless, tire-derived fiber has some limited applications such as fillers or stuffing for toys or furniture, as well as an additive for reinforcing plastics, rubber, and concrete. One processor expressed regret that the market for target practice backstops (a bale of mixed fiber) is low. Tire fiber has applications; however, the demand is much less than the available supply. Thus, most tire-derived fiber finds its way to landfills.

Because the commercial activity related to tire-derived fiber is very limited, the marketing knowledge is more concentrated than that of tire-derived steel. Consequently, sample sizes of fiber responses to the survey questions are considerably smaller than those for steel respondents.

The particle size of tire-derived fiber is a function of the process. Some cryogenic operations remove the fiber as a fabric rather than as short, individual strands of less than ½ inch, or as entangled, individual strands. The range of strand lengths reported runs from dust-particle size up to 5 inches, with the average of $^{46}/_{100}$ inches ± $^{22}/_{100}$ inches (8 responses).

Fiber separation and packaging equipment mentioned by processors in the survey is listed in Table 28.

Table 28. Technology to Recover Tire-Derived Fiber

Equipment or Operation	Percent	Counts
Air classification (e.g., blown, vacuum, aspiration)	81.3	26
Cotton gin	6.3	2
Baler	6.3	2
Density separator	3.1	1
Scalper (screen)	3.1	1
Totals	**100.0**	**32**

Tire-derived fiber recovered by processors has an average fiber content of $93^{3}/_{10}$ ± $3^{7}/_{10}$ percent, based on the responses. Because fiber has been difficult to market, many processors are not working diligently to efficiently segregate fiber and to generate high-quality product. The primary application for fiber appears to be TDF, either with the fiber left intact in the tire chip, added back in the mixture with rubber TDF, or as segregated-fiber TDF. Of the 22 responses, 15 companies (68 percent) are supplying fiber in some form to energy markets.

Fiber generation averaged $2^{2}/_{10}$ pounds per tire ± 1 pound per tire (16 responses). Those firms whose final processing step used a shredder generated much less fiber scrap, only a quarter of that for crumb rubber producers.

The bulk density of tire-derived fiber varies due to its compressibility. Many producers reported no bulk density value or had no idea of the density. The loose weight is in the range of 1 to 1½ pounds per cubic foot (1 response) and the baled material is about 31 to 32 pounds per cubic foot (1 response). Both polyester and nylon in resin form are significantly denser than water. However, the fibrous forms of the recovered resins contain many air voids. These resins inherently possess low-bulk density unless compressed.

The price range estimate for tire-derived fiber for all respondents is $21.00 ± $8.7 per ton (8 responses). TDF and TDF fiber compete against other types of fuels. A few of the responses reported TDF (in any form) sold at a discount to coal of about $1 per ton. From a small sample of three firms that are commercially supplying fiber as TDF (two of the firms add back-recovered fiber, and the third company does not separate the fiber), the mean market price of their TDFs is $20.80 ± $18.70 per ton.

The market price for commercial suppliers of fiber is $23.8 ± $5.4 per ton (3 responses).

Baling the fiber extends its economically feasible shipping distance. The average reported shipping distance to customers is 200 miles ± 196 miles, reflecting the small sample (3 responses) and the variation in local circumstances.

Disposal costs can be significant to commercial sellers, who frequently must dispose of fiber waste. Based on 34 responses, the average disposal cost is $31.9 ± $6.6 per ton. Also of significance, the average distance to a disposal site of $33^{3}/_{10}$ miles ± $16^{3}/_{10}$ miles (22 responses) appears to be much closer than that of finding commercial outlets for fiber.

Major Findings

The survey produced useful information for developing the scope of the tire-derived steel and fiber supply and determining the size of potential market applications for them.

Market Identification

The markets identified by the industry experts in the Task 2 survey are covered in the following subsections, along with their insights relevant to commercializing tire-derived steel and fiber.

Steel: The major market for tire-derived steel is the scrap metal market. It is the only application cited (44 responses of 55). Scrap steel is currently a potential market for some tire processors and not others. About 20 percent reported that no market (11 responses of 55). This is probably the result of an absence of local mills or of high rubber content in the steel scrap. Forty-three percent of the California responses for tire processors reported no market (3 responses of 7).

Based on almost 400 contacts with scrap metal dealers and foundries/steel mills, only one scrap dealer and one electric arc operation specifically reported using tire-derived steel. Other foundries/steel mills had considered using tire-derived steel before electing not to proceed (13 responses of 116). Similarly, 25 percent of scrap metal dealers had some prior experience with tire-derived scrap metal (10 responses of 40). Because scrap dealers or services prepared metal for mills in some cases, the mill operators may not know if the scrap contains steel from processed waste tires.

Most scrap buyers are not aware of the availability of tire-derived steel, nor have they had the chance to see its impact on their operations and blend chemistry. Many companies listed reasons that might limit the attractiveness of tire-derived steel as a commodity. About 17 percent commented positively on tire-derived steel and were open to further discussions regarding utilization (11 responses of 62). A number of scrap metal buyers suggested ways to overcome resistance to tire-derived steel, such as densifying steel from tires by compacting it (8 write-in responses of 71), and eliminating as much of the rubber as practical (53 responses of 62). Minimizing rubber contamination will encourage more interest by scrap steel consumers.

The steel scrap market tends to swing through its own demand curve, and supply imbalances can impact all suppliers of scrap. Waste tire steel with rubber attached is a low-end commodity and is very vulnerable when user demand is slack. Because of the potential limitations of tire-derived steel, the qualification process for buyer acceptance at a foundry/mill can be lengthy. The foundry/mill will first evaluate samples of feedstocks and consider the impact to the final product from copper or zinc. The environmental and operational staffs will consider blending and density issues and operational problems, such as potential emissions from rubber and sulfur. With many potential barriers and many circumstances for the customer to opt out arbitrarily, the process of acceptance by the user can be both lengthy and unsuccessful.

The primary use of tire-derived steel is as a mixed-grade scrap category 2 or 3, which has a global market. These categories are fairly low-grade materials with and without contamination such as oil. Some tire-derived steel is used throughout the swings in market demand. However, its best supply opportunity is in periods of especially high demand for the scrap metal markets. Limited exporting of steel from tires has also been reported. Scrap dealers are known to mix tire wire scrap with other steel scrap. The blend level is very low, usually less than 1 percent, due to the marketing risks. As a result, this type of blending of tire wire may not be practiced often. A number of scrap dealers handled tire wire from collection bins. They normally pick up steel without charge. The processors did not know the final destination.

The allowable rubber contamination varies by customer, from essentially no rubber (no residue) to as much as 20 percent. Generally, the ability to sustain a position in scrap steel sales improves as the attached rubber content drops from 10 percent to less than 1 percent. Locations without a steel scrap requirement or export location within 200 to 400 miles have little choice except to dispose of the material.

Generally, survey respondents said that there was no growth in the tire-derived steel market. Again, the market opportunity and growth expectations are likely different based on the rubber content. While foundry and mill requirements vary locally, with low rubber contamination, tire-derived steel can generally enjoy access to the scrap market. This is true even at the present time, when the market would be essentially closed to less attractive scrap materials.

Remelting of tire wire manufacturing scrap is practiced by at least one producer until the bronze or brass coating is applied, after which time the manufacturing scrap no longer meets the company’s own purchasing specifications. Another manufacturer sells coils of surplus wire for less than $20 per ton to wire brush and clothesline manufacturers that are looking for low-cost wire of almost any type.

Some markets such as California may be very difficult to penetrate because of stringent air emission standards. Looking outside of the country may be an option. However, constraints operate in other markets as well. A mill in Mexico that sources its scrap in the United States will not tolerate any rubber on steel, since it causes backfires on its feed line. The level of rubber contamination may also be limiting in marketing of tire-derived steel to more distant markets. One metal dealer is prepared to export rubber-free tire wire, paying $22 per ton, delivered to the dealer’s site. The issue of rubber contamination is particularly important to the scrap metal dealer. A customer-rejected load in a distant port is costly.

Once separated, tire-derived steel without a local market becomes a major cost center if it must be disposed. Thus, the best alternative for the steel may be to leave the steel in the rubber product. In TDF and civil engineering applications, the steel may accompany the product. However, some energy buyers are demanding the removal of up to 90 percent of the steel to keep their energy dollars focused and to eliminate metal buildup on combustion chamber grates. TDF competes against other fuel sources such as gas, oil, and coal. In one instance, TDF was reported to be replacing coke as an energy source at $180 per ton.

Civil engineering applications offer uses for unseparated tire steel that are economically attractive. Outlets for sections of tire are found in applications such as weights, tree tie-downs, flooring, and animal stall separators. The foregoing are all small markets, where the whole tire including the steel is used.

Fiber: Markets for tire-derived fiber are very limited. Fiber markets tend to be unique and limited in requirements. As a result, processors with markets for fiber are secretive. The TDF energy market and material applications (such as fillers and reinforcing materials) provide end uses that may connect with a supplier only in select geographical locations. No respondent pointed to any emerging application to sustain future growth. Several processors are or have sold tire-derived fiber as a reinforcing additive for concrete. The level of penetration is low. One firm is making rubber automotive products and using the fiber as a reinforcing material.

Fiber is a tolerable product for incorporation in some applications involving tire rubber. Crumb producers remove fiber when recovering rubber, but may reincorporate the fiber in selected applications. If steel contamination is present with the fiber, the potential marketing outlook is cloudy. Since the steel in fiber is normally sharply pointed, pieces in the product can be a liability. Therefore, low-end applications (for example, stuffing for toys) could be ruled out if human contact is possible. The other significant impurity for tire fiber is rubber. If the product is heated, the rubber can melt and cause problems for some potential applications. Imagination and creativity are needed to find local market opportunities for fiber.

TDF fiber is an energy product that competes with TDF itself and other energy sources. Makers of coarse tire materials such as TDF will add loose fiber to TDF as a way to increase the sales and eliminate a potential disposal cost. Fiber is not separate in coarse tire materials; that is, it remains incorporated with the rubber. These materials include TDF, civil engineering products, and the variety of products with cut tire sections that form the end product.

As shown in Table 29, the largest market application (21 percent) for tire-derived fiber consists of its use as fiber TDF. Almost one-quarter of the respondents cited no markets for tire-derived fiber.

Table 29. End Uses Identified for Tire-Derived Fiber

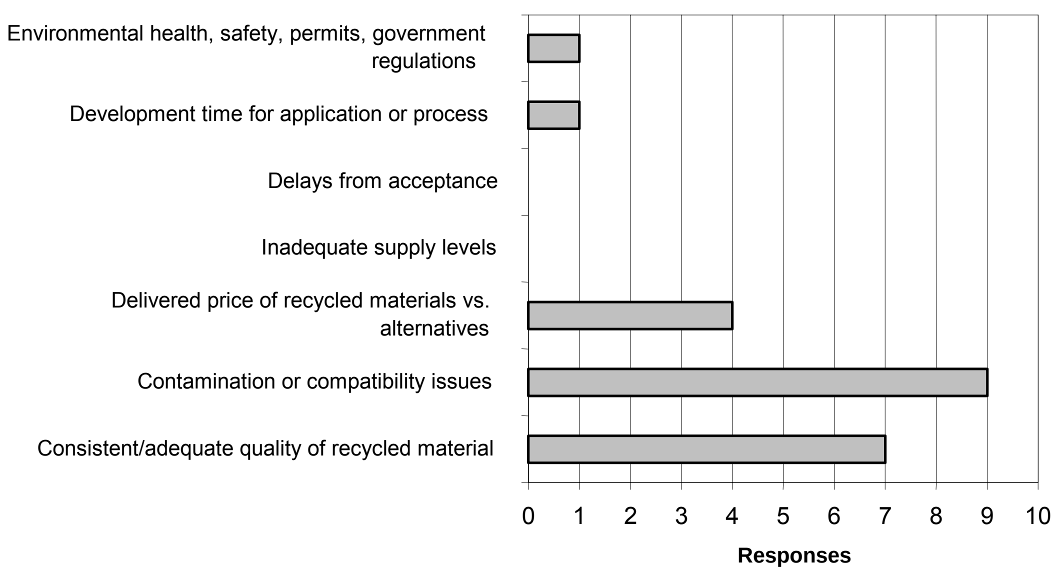
Application	Percent	Counts
Fiber TDF	21.4	15
Rubber	10.0	7
Concrete additive	5.7	4
Carpet	4.3	3
Soil amendment	4.3	3
Proprietary use	4.3	3
Sound deadening	4.3	3
Blanket	2.9	2
Insulation	2.9	2
Target backing	2.9	2
Recycled to plastics	1.4	1
Mulch	1.4	1
Composite	1.4	1
Adhesive reinforcement	1.4	1
Asphalt strengthening	1.4	1
Toy stuffing	1.4	1
Packing	1.4	1
Flooring additive	1.4	1
Furniture stuffing	1.4	1
None	24.3	17
Totals	**100.0**	**701**

Barriers and Issues

The surveys specifically asked about barriers to—and issues surrounding—the marketing of tire-derived fiber and steel. This portion of the survey produced the greatest impact on, and response from, the respondents. Many of the salient comments from the survey are covered in this section.

Steel: Barriers to reuse of belt steel are of slightly greater magnitude than those of bead steel, as illustrated by the data in Figure L. This assessment stems from opinions of respondents that belt wire is thinner and more difficult to recover in a form acceptable to mills. The three largest issues for both types of tire steel are low purity (for example, content of attached rubber and alloy coating are too high), selling price too low, and cost of equipment is too high. The types of high-priced equipment include compaction equipment to densify the recovered steel from tire recycling operations or processing equipment to better remove rubber from the steel.

Figure L. Processor View of the Barriers and Issues for Tire-Derived Steel



The survey captured additional impressions from the end users about why rubber contamination is a barrier to sales of tire-derived steel. Table 30 breaks down the issues and shows the response by percent.

Table 30. Markets View of the Commercial Limitations of Tire-Derived Steel

Issues Reported for Attached Rubber	Percent	Counts
Sulfur	41.5	27
Baghouse	27.7	18
Smoke	12.3	8
Specifications/metallurgy	9.2	6
Safety	6.2	4
Operational issues	3.1	2
Totals	**100.0**	**65**

Sulfur emissions for foundry/steel mills are the number one reason cited for limiting the use of tire-derived steel. Most concerns with sulfur involved emissions. Respondents questioned the impact of sulfur in tire-derived steel on their slag operations (which trap sulfur) or on the properties of the final metallurgy of the steel. While sulfur is a major restriction in the sale of tire-derived steel, 19 percent of responses were positive in tone, suggesting that sulfur (and, therefore, rubber contamination) at some level is acceptable (5 responses of 27).

Combustion of rubber causes two potential emission problems. The first is smoke that is very thick and tar-like. The second is that the combustion products will clog baghouse filters or overload them. Rubber may burn at the wrong point in the operation; for example, on a feed line to the melt. This could create safety and operational problems. Some respondents speculated that induction furnace operations would not have the losses from low-density tire-derived steel that are potential limitations in electric arc or cupola furnaces. However, among the firms surveyed were induction furnace operations. One ruled out its operation because of potential fires with rubber in the preheater. Another safety concern stems from the potential of auto-ignition and fires in mixtures containing steel, rubber, and moisture. If the tire-derived steel is rubber free, auto-ignition cannot occur.

Many foundries express concerns about having to blend feedstocks. Others were concerned about maintaining their preferred chemistry in the melt bath when adding coated tire wire or other metals in the tire-derived steels. Some of the foundries were more sensitive than others regarding this issue. However, 23 percent were not restrictive or welcomed some bronze or brass coatings in their operations (10 responses of 43). Foundries will blend as needed. Many foundries use custom service companies to manage the activity; blending is a cost item the company can outsource in order to lower its costs. All operations resist more blending than is necessary because maintaining and managing inventory adds cost.

Finding a market that can tolerate a combination of rubber, sulfur, and alloys will be challenging. Less than 1 percent of responses showed tire wire actually being used (1 response of 117). Where used in a blend, tire-derived steel composed less than 1 percent of the charge (2 responses).

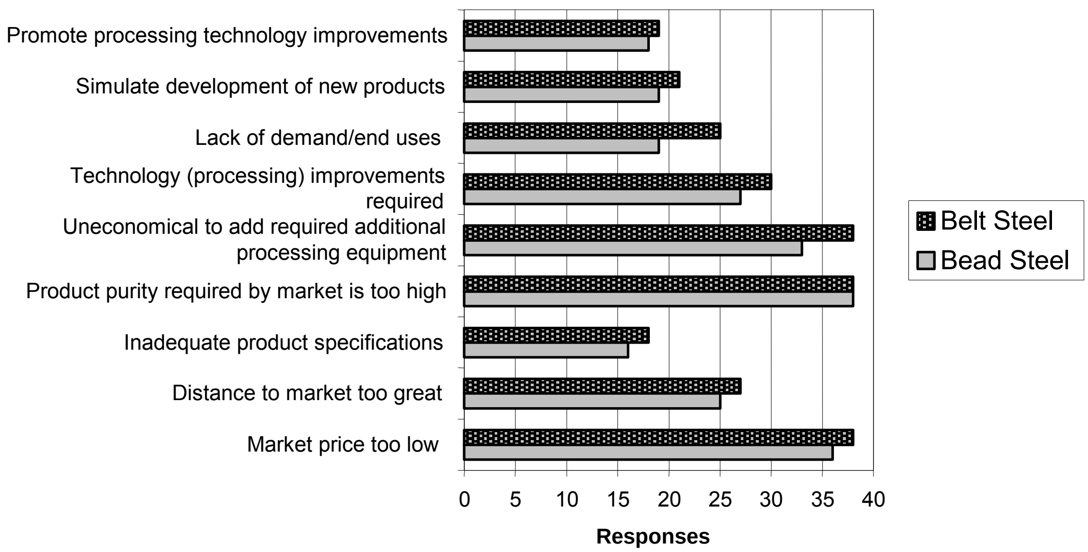
Another broad restriction on use is the physical form of tire-derived steel. Only a small number of furnace operators are willing to accept major losses using small pieces of steel. Remelting is vulnerable to vaporization in electric arc furnace operations, while low-density feedstock can be blown out of the melt bath in cupolas. Operators may be able to reduce losses of low-density feedstock by as much as 30 to 40 percent by stacking the charge with heavier scrap, such as flat plate. Density of the charge is an important variable identified by the survey. Filling the charge chamber must be handled in as few steps as possible. If the feed is low-density material, more transfers of material must be made to achieve a given mass feed rate, thereby increasing operating cost.

Provision of high-density scrap is a priority for most furnace operations. Typical competitive scrap is composed of shredded auto bodies that become metal pieces with 2- to 4-inch diameters. Electric arc furnaces may use 2- to 3-inch plate steel to prevent vaporization. A few plants use loose feed similar to tire wire. Most companies will not accept wire. One method of increasing the density of tire-derived steel is to compact or bale it. Not only does this improve handling and decrease losses and spills (safety and operational issues), the denser packaging reduces potential losses in the furnace. Briquettes were referenced as the preferred feed for some operations, and they command a top price in scrap markets. The size of the bale, bundle, or compacted steel from tires is an important consideration because many foundries have feed openings with less than a 2-foot cross-section.

Chopped and compacted bead wire is the most saleable steel from tires. Some operations have difficulty cutting bead wire or trying to compact it. One operator mentioned destroying a $125,000 compactor with bead wire. Another operator mentioned capital costs as high as $300,000 for suitable compaction equipment. Such investments are not feasible without a committed buyer of the material.

Producers and users responding to the survey showed great concern about tire-derived steel contamination. This is due to the attached rubber, sulfur, or coatings of brass or bronze, as reflected by the responses summarized in Figures M and N. End users frequently identified emissions of smoke and sulfur (in the gas as SO_2 and in the slag) as potential limits on the use of tire-derived steel.

Figure M. Producer View of the Barriers and Issues for Tire-Derived Steel[0]



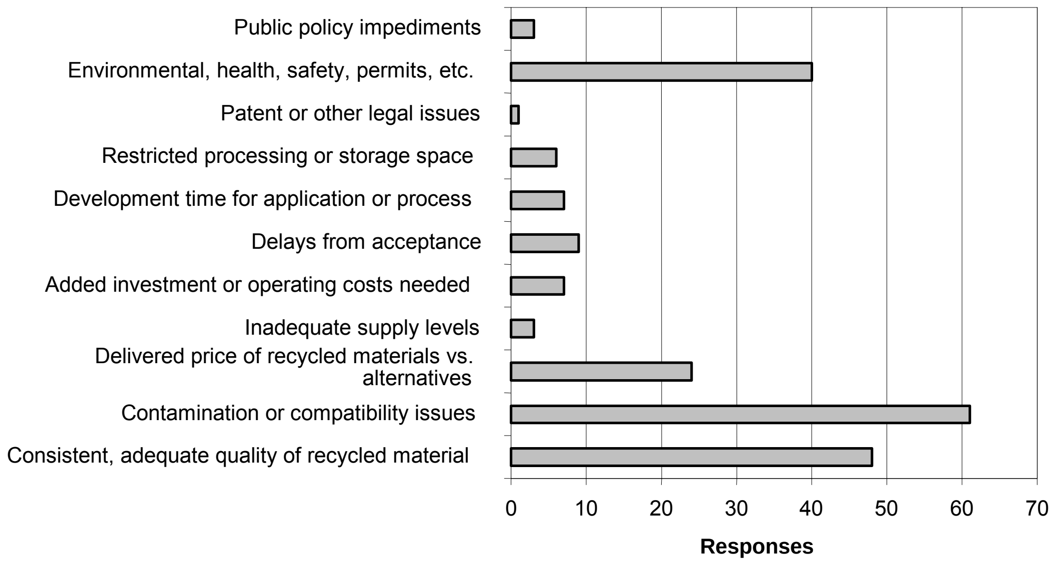
In December 2002, the U.S. Environmental Protection Agency went forward with a request for comment on a proposal that might significantly restrict emissions from steel-making operations. Several mill operators pointed out that in the worst-case scenario, the potential regulation would greatly reduce their options in using scrap steel. Tire-derived steel, with its emission-related issues, is already vulnerable. According to at least two respondents, tire-derived steel is likely to be frozen out of this market if the proposal is adopted as a final regulation without change.

Many respondents described the risk of auto-ignition of inventory from the mixing of steel, rubber, and moisture, and the risk of fires from pre-combustion of rubber. One mill that had taken many truckloads of tire wire scrap—delivered free of charge—stopped using tire-derived steel. The operators were concerned about auto-ignition of stockpiled feedstock and the resulting negative publicity.

Loose tire-derived steel introduces handling and safety problems. Respondents mentioned overhead spills of loose tire wire, punctures of vehicle tires and conveyor belts, and problems with the material on the foundry floor and in the storage yard.

Compatibility issues identified by respondents included potential metallurgical problems associated with alloy coatings on tire wire. Some foundries and mills did not want to affect the chemistry in the final products by introducing any alloy coating. Others were concerned about the delivered physical form of the tire-derived steel.

Figure N. Markets View of the Barriers and Issues for Tire-Derived Steel



Another major issue for producers and the marketplace is the consistency of the product supplied by processors. The characteristics of test samples frequently do not match those of delivered loads, and variations occur among load. ISRI has developed a standard for grades of tire wire and is developing an informational brochure for the industry. Before this standard-setting activity, no uniform industry specifications were available for tire-derived steel. Few company standards existed. The industry represented by the markets survey respondents is largely unaware of this activity, as reflected by the data in Table 31.

Table 31. Standards for Tire-Derived Fiber or Steel

Status of Standards	Yes	No	Counts
Company specifications	5.9	94.1	68
Industry standard in place	9.5	90.5	21
Any industry developing standards	0.0	100.0	51

This ISRI activity has the potential to educate the marketplace and to counteract the lack of information and the misinformation circulating through scrap metal markets. Only 17 percent of the respondents to the market survey claimed experience with either tire-derived steel or fiber (32 responses of 189). The experience within the total industry population will be much lower since the surveyed contacts were identified prior to contact as being in a position to know about the subject.

Scrap dealers are important to getting the word out about commercial opportunities for tire-derived steel, as interpreted from the data in Table 32. A number of other mechanisms also come into play. Government resources have not been important, nor to date are Internet exchanges or company Web sites. The message from the survey is that, at this stage of development, most of the effort in finding and communicating commercial opportunities rests with the processors themselves. As comparably small entities with limited resources, the ability of processors to identify and qualify their products with sophisticated buyers such as large foundries or mills with very specific requirements is a daunting challenge. Since some of these local markets may not contain a single opportunity, the effort may be fruitless, regardless of the talent and expertise of the processor.

Table 32. Industry Commercial Communications—Buying or Selling Interest

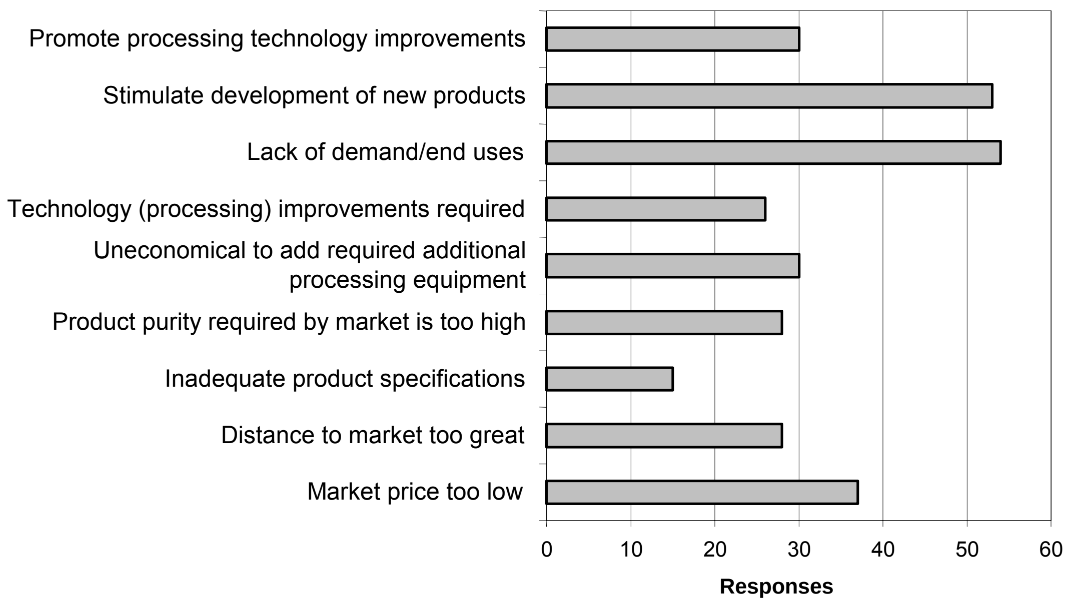
Methods of Exchange	Percent	Counts
Scrap dealers	24.0	12
Tire recyclers	24.0	12
Long-term relationships	18.0	9
Competitors	12.0	6
Resellers, distributors, or trader communications	6.0	3
Word of mouth	6.0	3
Consultants	2.0	1
Established contracts	2.0	1
Industry publications	2.0	1
Reprocessors of steel or fiber	2.0	1
Third-party Internet exchanges, trading platforms, or offers to buy or sell listing site	2.0	1
Company Web sites	0.0	0
Government entities	0.0	0
Totals	**100.0**	**50**

The image is not helped by piles of a high rubber-content tire wire inventoried around the country at processor, scrap dealer, and customer sites. The picture reinforces the notion held by some users that steel from tires is a marginally acceptable or entirely unacceptable product. Similarly, there were many comments by respondents that tire processors have contacted them, provided samples, and never returned. The professional standards in dealing with scrap metal markets must be raised to counteract the poor business practices of some entrepreneurs.

Perception and professionalism are also issues with the public and local politicians. A number of processors, recyclers, and collection companies mentioned that they were being removed from their recycling sites. Their businesses suffered when permits for burning TDF were not forthcoming, or they were harmed in other ways that limited their operations.

Fiber: Tire-derived fiber has a series of limited markets, with the supply of fiber greatly exceeding the demand. Thus, as shown in Figure O, respondents see the need for outside support to stimulate new product development that goes hand in hand with lack of end uses of sufficient size. The low market price of fiber reflects the weakness of its existing applications.

Figure O. Processor View of the Barriers and Issues for Tire-Derived Fiber

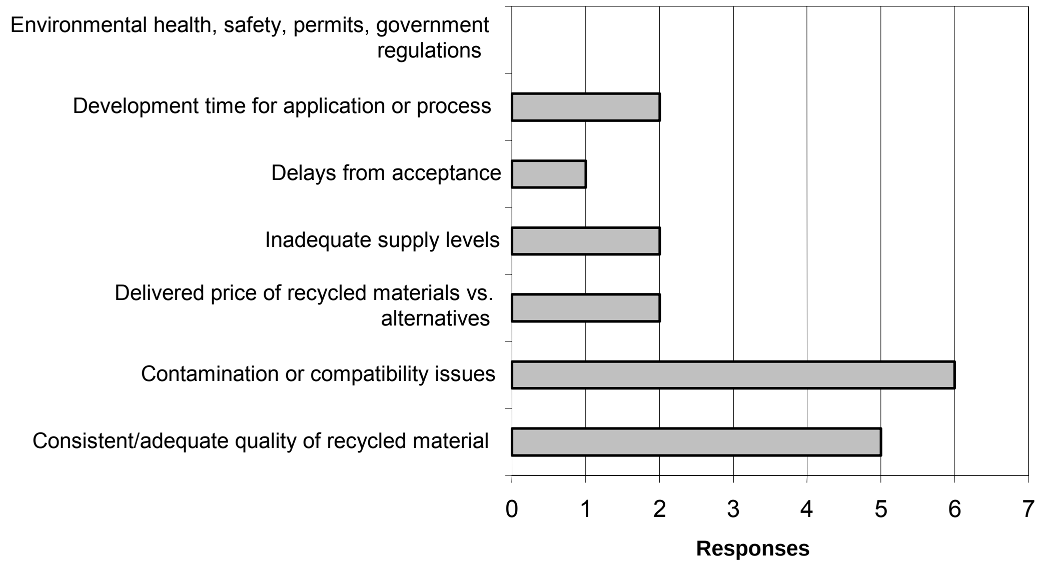


Because of the lack of markets, processors generally said that they did not try to produce the highest quality fiber possible. Others described the difficulty of maintaining the quality of fiber through all of the separation steps. The rubber and steel strands can become entangled in the fiber and become very difficult to remove. Some processors reported that their fiber is devoid of rubber, steel, and dirt. However, not all fiber is dirt free. Most potential customers are sufficiently concerned about liability that they do not want to purchase fiber with small, sharp particles of metal in it, unless the application does not involve human contact.

Both the producer and markets respondents, Figures P and Q, respectively, cited contamination/compatibility issues and feedstock consistency as the two primary barriers/issues related to reuse of fiber.

The investment barrier surfaced in some end user comments regarding the problem of feeding tire-derived fiber to TDF conversion systems. In either form, loose or baled, tire-derived fiber may require a new feed line at the consumer’s site. Processors mentioned the reluctance of power, paper, and cement plants in making the needed investment. This is true regardless of the purchase price of the TDF, and even if the fiber is delivered free of charge. Investment capital for a baler, when the market for the fiber as TDF is unclear, is very hard to justify.

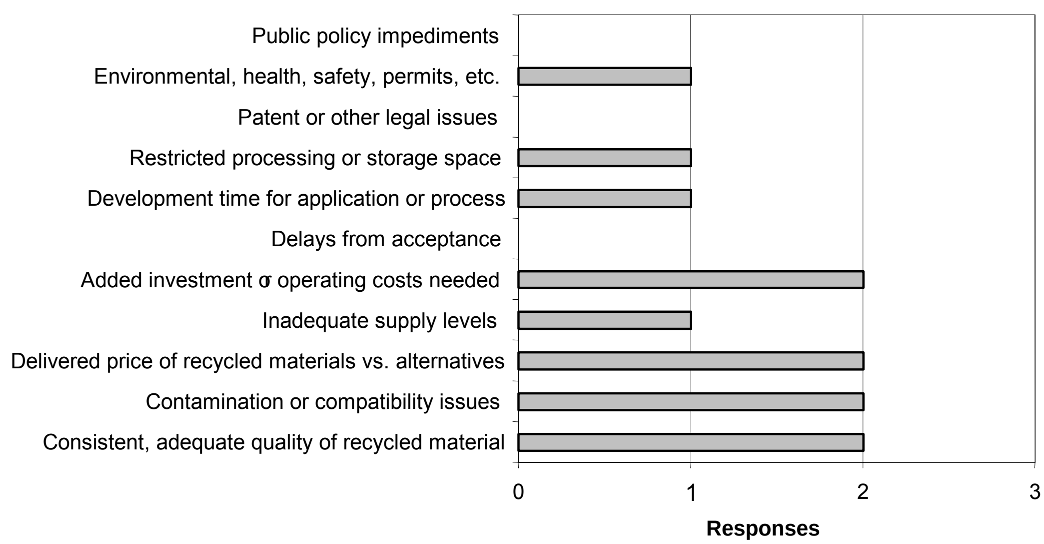
Figure P. Producer View of the Barriers and Issues for Tire-Derived Fiber



Economic Drivers

Several survey respondents declared that a necessary key to profitability is the way in which processors handled their waste streams; that is, tire-derived steel and fiber. About 20 to 40 percent of the production output of a processor can be in the form of steel and fiber. If this substantial output has no commercial home, it becomes a major drain on cash flow rather than a potential contributor to profitability. Since steel and fiber sales are normally contracted on a spot market basis, no long-term market commitment exists. Little justification exists for making

Figure Q. Markets View of the Barriers and Issues for Tire-Derived Fiber



cleaner finished products that would help sales. Finding revenue streams for tire-derived steel and fiber may be critical to the long-term success of the crumb rubber producers.

Steel: Earlier in the report, Figure F showed the disparity in the production capacity of processors. Production ranges from thousands of tires per hour to only one to two per hour. The economies of scale favor the larger operations as long as they maintain high rates of utilization of the equipment that they add when entering into new business development initiatives.

Rubber recovery processes differ somewhat. Companies using ambient grind processes claim that they can produce clean tire-derived steel. On the other hand, some companies use the more expensive cryogenic processes; cryogenic processes are frequently mentioned as able to achieve a cleaner recovery of steel and of fiber. Extent of processing experience likely is a factor in the preferences shown for technology selection.

Many government programs run by states and Canadian provinces promote tire recycling. Poorly designed incentive programs will encourage weak recyclers that are sustained only by the incentive. These companies would quickly depart, should the program expire. Incentive systems may be necessary, for example, to overcome the cost to operate recycling facilities in a high-cost area. The incentives could encourage recovery of tires from tire dumps that require high labor costs to extract feedstock.

California, as an example, has some potential outlets for tire-derived steel. Without any initiatives, significant commercial incentives are already in place if marketable steel is recovered (an example would be if the steel is sufficiently clean and if markets can tolerate the trace metals, or dilute their effect). Overcoming a $30 per ton cost for disposing of tire and fiber wastes, by just giving away these materials, substantially reduces out-of-pocket expense. While freight cost to the customer may reduce or eliminate netbacks, clean tire-derived steel has market opportunities. If tire-derived steel could regularly compete without discounts due to rubber contamination, export opportunities reportedly exist in the $22 per ton range. Spot sales opportunities of $40 to $60 per ton are available. Thus, the marketplace already has significant motivation to clean tire-derived steel to achieve these higher selling prices.

Prices of steel reported in the end user survey generally are similar to those found in the processor survey, as shown in Table 33. Price will be determined locally based on competitive conditions in that market. Thus, across the country a number of price tiers are likely to be maintained. Manufacturing waste (home scrap), at $20 to $25 per ton, might represent a benchmark material category for pricing tire-derived steel in the United States. The foregoing cost range is certainly an indication of market price for very clean steel from tires.

Table 33. Markets View of Tire-Derived Steel Pricing

Material	Price Range ($/ton)	Counts
Home scrap belt wire	20 to 25	2
Waste tire steel (containerized, shredded)	0 to 60	7
Waste tire steel (wire or belt bundles)	0 to 22.5	2

Original thinking is required to define a business strategy and operation setup that is sustainable and profitable in recovering clean steel and fiber. The best local situation may not justify fiber or steel recovery. In the survey, many processors felt that there was a strong incentive not to invest in equipment for making a fairly clean tire-derived steel and fiber separation. Instead, the economics favored concentrating on producing TDF and civil engineering products that incorporate steel and fiber, rather than separating them.

Among comments on operational considerations, several suggestions were made by respondents. Employing a debeader lowers maintenance costs, down time, and blade replacement by eliminating tough bead wire from streams entering size reduction equipment. Bead wire is pulled cleanly from the tire except for a small attachment where the bead is grasped in the pulling operation. Some operators lop off this piece as well to create very clean tire-derived steel. Processors indicated that drawbacks of using a debeader include a lowering of processing line production and safety risk.

Another suggestion offered by several contacts was to package the steel from tires into forms that are more easily handled. Bundling bands the tire wire. Compacting equipment densifies it, as well as creates a packaged form (for example, block) for safe and easy transfer and handling. One system creates a brick-sized piece (briquette). Another shape is a 2 x 2 x 3 foot block. Compacted material can command a premium price, for example, up to $140 per ton. One foundry identified in the survey was designed to receive and use only briquettes, not necessarily sourced from tire wire.

The survey identified several technologies available for use in cleaning rubber from steel. Ace Equipment Company is prototyping a combustion chamber for burning rubber from the wire while maintaining a clean environment. Bi-Metal Corporation sells a process called the "Clean Wire System" that some industry processors are now using.

Fiber: While steel has clearly defined outlets in the scrap markets, the market for tire-derived fiber is less well established and more diverse. As a mixed fiber, it competes more on price and form value (that is, physical form) than on its properties (for example, fiber length or mechanical strength). This analysis concentrates on a few representative applications rather than attempting to screen all potential energy, filler, and reinforcing applications proposed for tire-derived fiber.

The key for some of the applications is finding low-cost methods of delivery, while minimizing the contamination of the product with metal and rubber, and controlling water content.

A key issue in the commercial market for tire-derived fiber is the shipping distance. Another issue is the market boundary: if established by freight cost, does it provide sufficient levels of demand? For many processor respondents, their local market frequently does not meet this criterion.

A few processors in the survey are successfully selling tire-derived fiber. At the same time, the survey also uncovered several beneficiation techniques for cleaning fiber.

As in the case of tire-derived steel, the majority of recovered fiber has a value much less than its potential. While it is unrealistic to compare the value of manufacturing waste (home scrap) with tire-derived fiber, values of three types of products reported in the survey are shown in Table 34 as a point of reference. Because there is no easy method of segregating fiber recovered from tires by fiber type, the resulting post-processor material is a mixed fiber blend of variable proportions. Tire-derived fiber will probably never achieve the recycle value of a single grade and resin type reusable in traditional single-resin fiber applications. Tire-derived fiber competes as mixed fiber with other non-descript materials on the basis of price. Thus, processors are normally pleased to avoid disposal cost and simply give the fiber away.

Table 34. Markets View of Tire-Derived Fiber Pricing

Material	Price Range ($/ton)	Counts
Home scrap tire polyester fabric/fiber	75	1
Home scrap tire nylon fabric/fiber	130	1
Tire-derived fiber	-0.5 to 0	3

Based on the current successes in placing tire-derived fiber, the supply may exceed the potential of give-away outlets. Disposal of the material may continue to be the norm. TDF fiber may become an application that could consume most of the available production if the water content can be consistently limited; if acceptable, economical methods of densification are implemented; and if existing fuel feed systems can be utilized. Some utilities and paper and cement facilities are already firing whole tires and processed TDF. Thus, they would be natural candidates to consider as well for fiber TDF. In such cases, the value of TDF fiber would be based upon heat content and could be potentially discounted on the basis of difficulty of handling, etc.

Geographical Differences

The processor contacts included 127 companies in California that appeared to be involved directly with recycling or processing of tires. Of these, 5 were either defunct or had non-working contact numbers, leaving 122. Detailed responses were received from 46 companies, including 12 processors or tire recyclers.

The breakdown of the survey by area is shown in Table 35. The core group in California includes 12 processors with the potential of producing tire-derived steel and fiber and 4 potential scrap steel buyers.

Table 35. Breakdown of Survey Respondents by Geographical Area

Core Groups	Counts		
	CA	Rest of U.S.	International
Markets			
• Foundries	4	67	0
• Scrap dealers	19	6	2
• Other	4	2	1
Totals	**27**	**75**	**3**
• Experienced: Yes	8	19	2
Processors			
• Processors/recyclers	12	67	11
• Other	4	17	3
Totals	**16**	**84**	**14**
• Average, start year	1989	1986	1985
Producers	3	21	1

A dozen California processors with potential to produce tire-derived steel and fiber responded to the survey. A lesser number provided data on market price and disposal cost relative to fiber and steel, as shown by the data in Table 36. Based on the returns, California tire processing plants are smaller, produce lower quality tire-derived steel, and receive a lower price than processors in the rest of the United States or outside of the United States. Disposal costs for either tire-derived steel or fiber are about $10 per ton lower than the median for the rest of the United States.

Based on the results shown in Table 37, processors from California have a distinctly lower marketability of their tire-derived steel than those reporting from the rest of the United States, or in international locations. However, the low marketability of fiber reported in California is comparable to levels elsewhere.

The survey responses concerning market outlook are a poignant indication that California may be a particularly difficult market for tire-derived steel and fiber. Given that the quality of tire-derived materials generated by California processors is apparently below the national average, a lower market price and potential for sale may result.

Table 36. Averages of Selected Parameters for Tire-Derived Steel and Fiber Broken Down by Geographical Area

Crumb Rubber Producers and Tire Recyclers Only				
Location	**Daily Passenger/ Truck Tires (PTE) Processed**	**Fiber Content (percent)**	**Steel Content (percent)**	
CA	3,590	83	83	
Rest of U.S.	10,000	95	89	
International	4,470	82	95	
	Counts			
CA	8	3	3	
Rest of U.S.	44	10	27	
International	7	2	6	
Steel	**Market Price[a] ($/ton)**	**Disposal Cost ($/ton)**	**Distance to Market (mi)**	**Distance to Disposal (mi)**
CA	16.60	23.90	10	29
Rest of U.S.	33.80	31.30	103	38
International	44.10	27.20	81	11
	Counts			
CA	6	5	2	3
Rest of U.S.	34	23	19	15
International	5	4	4	2
Fiber	**Market Price ($/ton)**	**Cost to Dispose ($/ton)**	**Distance to Market (mi)**	**Distance to Disposal Site (mi)**
CA	nr	23.90	nr	29
Rest of U.S.	19.40	33.00	150	41
International	7.00	21.80	300	13
	Counts			
CA	0	5	0	3
Rest of U.S.	6	18	2	13
International	2	5	1	4

[a] The average market price for steel includes end user estimates.
nr = none reported

Table 37. Percentage of Processors Recycling Tire-Derived Steel and Fiber

Location	Percent[a]		Counts	
	Steel	Fiber	Steel	Fiber
CA	36.0	38.5	13	13
Rest of U.S.	59.4	40.4	55	57
International	78.9	33.3	10	9
Totals	**58.0**	**39.2**	**78**	**79**

[a] Percentage respondents that reported recycling rather than disposing of tire-derived steel or fiber.

Taking a more detailed look and splitting the processors into groups of differing production capacity, it is clear that larger operations are more likely to recycle tire-derived steel. This is reflected by the data and ratios shown in Table 38.

Table 38. Processor Results—Recycling of Tire-Derived Steel as a Function of Capacity and Geographical Area

Size (PTE Daily)	CA		Rest of U.S.		International		Totals	
Percentage Recycling or Disposing of Tire-Derived Steel								
Larger than 3,000	60	40	100	0	65	35	68	33
Below 3,000	29	71	67	33	67	33	57	43
	Counts							
Larger than 3,000	3	2	4	0	20	11	27	13
Below 3,000	2	5	4	2	10	5	16	12
Tire-Derived Steel Recycling to Disposal Ratio								
Larger than 3,000	1.5		Infinite		1.8		2.1	
Below 3,000	0.4		2.0		2.0		1.3	

Although not as pronounced as in the case of processing capacity, it appears that with a certain amount of experience, operations are more likely to recycle steel (see Table 39). In California, among the firms represented by the survey, recycling of steel is less likely than in other geographical areas.

Table 39. Processor Results—Recycling of Tire-Derived Steel, by Plant Experience and Geographical Area

Experience	CA		Rest of U.S.		International		Totals	
Percentage Recycling or Disposing of Tire-Derived Steel								
Above 3 years	44	56	75	25	69	31	66	34
3 years or less	33	67	100	0	0	100	50	50
	Counts							
Above 3 years	4	5	6	2	31	14	41	21
3 years or less	1	2	2	0	0	1	3	3
Tire-Derived Steel Recycling to Disposal Ratio								
Above 3 years	0.8		3.0		2.2		2.0	
3 years or less	0.5		Infinite		0.0		1.0	

The California and international respondents have a more positive outlook for the available supply of tires than the rest of the United States, as shown in Table 40. The international group is the most optimistic about the future market for tire-derived steel, while California processors are the least enthusiastic. In the case of fiber markets, processors in all three geographic groupings are pessimistic, with the greatest pessimism expressed by California processors.

Table 40. Markets Outlook by Geographical Area

Tire Supply	Increasing	Steady	Decreasing		CA Correlation	Counts
CA	4	3	1			8
Rest of U.S.	15	21	6		0.737	42
International	4	3	0		0.996	7
Market Demand	**Good**	**Fair**	**Poor**	**No Market**		
Steel						
• CA	2	2	9	4		17
• Rest of U.S.	34	20	31	29	0.310	114
• International	6	1	4	2	0.125	13
Fiber						
• CA	0	1	2	6		9
• Rest of U.S.	2	6	13	26	0.990	47
• International	0	2	1	3	0.834	6

Dataset correlation to California: A number near 1 signifies a good predictor of the other relationship.

The survey responses suggest that California may be a particularly difficult market for tire-derived steel and fiber. Given that the quality of tire-derived materials in California is apparently below the national average, a low market price and low potential for sale would be the expectation.

At the time of the survey, at least three California processors were recycling bead steel and at least two were recycling belt wire. Bead wire is easier to recycle than belt wire because bead wire recovered by debeading equipment yields steel with a very low rubber content.

Since no current uses of tire-derived steel were found in California, indications are that recovered tire-derived steel is being recycled out of state or through offshore export markets. Since both scrap users and dealers blend steel to achieve acceptable metallurgy, the actual market in California for tire-derived steel could expand due to the potential opportunities that blending represents. Also, 11 scrap dealers said that they would try to move tire-derived steel if it contained no rubber or if the rubber content was limited to 1 to 5 percent (this level of contamination is technically achievable, based on the results of the survey). The dealers also commonly mentioned compaction and 2 to 6 inches maximum wire lengths as desirable product characteristics. If the foregoing specifications were to be met, feasible markets for California processors include mills in California, the Pacific Northwest, Mexico, and export locations. California has about six foundry opportunities for tire-derived steel where tire steel with low rubber contamination steel might be acceptable.

Chapter 3. Supply/Demand Analysis—Methodology and Results

This chapter presents the results of a supply and demand analysis (Task 3) for tire-derived steel and fiber in California, along with comparisons of conditions in the United States and the world.

Appendix G lists new contacts with trade associations, end users, scrap dealers, tire processors, recyclers, and related firms. A number of experts first contacted in the Task 2 survey process were contacted again to confirm the comments that they made concerning earlier tasks.

The discarded tires from which the steel and fiber by-products are derived have been produced over many years by different tire companies. Tire specifications, brand, model, size, and performance grade vary with vehicle type, and automobile company. The steel and fiber composition of these tires thus varies with the tires processed. Tire-derived steel consists of bead, body, or belt wire, as well as mixtures. Rubber, ranging from trace amounts to more than 30 percent, may remain attached to the scrap steel and be shipped with it to commercial markets. Tire-derived fiber consists of mixed fiber types that are primarily polyester, but may include significant amounts of nylon and small concentrations of rayon, aromatic polyamide (for example, Kevlar®), and/or cotton.

Supply

Estimates of potential supply—or generation—of waste tires in California were performed to identify the range of quantities of tire-derived steel and fiber and, therefore, provide a context for analysis of, and judgments regarding, market demand. Estimates of supply were calculated through the year 2007. Because much of the potentially recoverable steel and fiber is and would be generated as a by-product of crumb rubber production, an estimate of crumb rubber production in California for 2007 was also performed. This section discusses three methods of analyzing the number of waste tires generated in California and presents results of the analysis.

Key Resources and Assumptions

The accuracy of estimates of waste tire generation in the United States is not known because of a lack of reporting and accounting systems to record, track, and compile data on waste tire generation. Lacking such systems and direct data, waste tire generation must be estimated indirectly. The analysis presented in this section is based on public information and data obtained primarily from the California Department of Transportation (Caltrans), RMA, the CIWMB, and the California Department of Finance (DOF).

In a report dated December 2002, RMA estimated the total quantity of scrap (waste) tires generated in the United States in 2001 to be approximately 281 million PTEs ("U.S. Scrap Tire Markets 2001", 2002, p. 8). The same report states that, based on U.S. census data, a ratio of tires generated to population yields a constant of approximately 1 tire consumed per capita per year. This average rate of generation was confirmed as representative based on 2001 data ("U.S. Scrap Tire Markets 2001," 2002). After further analysis and the inclusion of data from scrapped vehicles, as well as replacement tires, RMA concluded that this ratio was applicable on a nationwide basis. In fact, the estimates provided by RMA have become the basis upon which some states in the United States estimate the rate of generation of waste tires in their states. However, it is important to note that the 1-tire-per-capita rate is an average value representative of waste tire generation in the United States, and it may not necessarily be representative of generation in California.

A presentation made by the RMA to the California Department of Energy stated that in the year 2001, the average tire life was 43,000 miles (Norberg, 2002). Similarly, *The Tire Review* and *Commercial Tire Systems* report commercial tire life spans in the range of 40,000 to 400,000 miles, depending on the application (Carley, 2000 and Goodyear, 2002.) Given that retreadable commercial tires generally average at least two retreads per casing, CalRecovery conservatively estimated that each medium and heavy truck casing was retreaded twice before being scrapped. The assumption of retreading only twice makes an allowance for the fact that some commercial truck tires would not be retreadable due to conditions, such as casing damage, that make retreading infeasible.

Population data and projections used in the analysis discussed later in this section were obtained from the DOF (Department of Finance, 2001). The DOF is the official source for California population data. As described subsequently, CalRecovery also computed some estimates of population data based on DOF data.

Data related to number of registered motor vehicles and number of vehicle miles traveled (VMT) by vehicle types (weight classes) in California were obtained from a report produced by Caltrans, *California Motor Vehicle Stock, Travel and Fuel Forecast* (1999). The data in the report are used for purposes such as estimating fuel tax revenues, transportation and traffic planning, and estimating air emissions.

Lastly, data from CIWMB was also used in the analysis (*Waste Tire Management Program: 2000 Annual Report, 2001*).

Methodology

Three methods were used in the effort to accurately quantify the annual waste tire supply in California.

Method 1

The first method is based on a waste tire unit generation factor reported by the RMA and California population data to estimate the annual supply of waste tires.

1. The unit generation rate of 1 PTE per capita was multiplied by the annual population data provided by the DOF through 2000, as well as by our estimates of annual population based on DOF projections, for the years 2005 and 2010. (Although the DOF provides annual population data for the past years, future population estimates are available at only five-year intervals.)
2. Yearly population data were broken down to ascertain yearly growth rates between 2001 and 2005.
3. The average of these growth rates was applied to 2002 through 2005.
4. These procedures were then repeated and applied to data between 2005 and 2010 to ascertain population estimates for 2006 and 2007.
5. These population figures were then multiplied by the RMA unit rate of 1 PTE per capita to provide estimates of the waste tire generation. Recoverable steel and fiber were estimated assuming 100 percent recovery.

Method 2

The second method of estimation used information available for total vehicles registered, average VMT, and the average lifespan of a tire.

Total VMTs were multiplied by the appropriate PTE factor (where 1 PTE was equal to a 20-pound waste tire) for the various types of vehicles analyzed and then divided by the average life of a tire. The analysis evaluated six vehicle classes (autos, light vehicles, medium-light vehicles, medium vehicles, heavy vehicles, and motorcycles). Table 41 illustrates the information supplied by Caltrans and the conversions used in the calculation. Medium and heavy-truck tires were assumed to last twice as long as passenger tires and to be retreaded twice. Once calculated, the values were scaled forward three years to account for the fact that a passenger vehicle tire with an average life of 43,000 miles today will not be "scrapped" until 43,000 miles have been driven. With California passenger vehicle drivers averaging 13,200 miles per year (*California Motor Vehicle Stock, Travel and Fuel Forecast*, 1999, pp. 21 and 25) drivers purchasing tires today will have them for approximately three years before discarding them.

Table 41. Estimate of the Annual Number of PTEs Generated in California Using Method 2 (2003)

	Auto[a]	Light Vehicle [a]	Medium-Light Vehicle[a]	Medium Vehicle [b,c]	Heavy Vehicle [b,c]	Motor-cycle	Totals[d]
No. of vehicles	16,450,000	33,940,000	1,964,000	369,000	127,000	386,000	
VMTs (millions)	217,149	42,906	25,752	9,056	7,795	848	
Average no. of tires per vehicle	4	4	6	6	14	2	
Conversion factor to PTEs	1	1	1	5	5	0.5	
PTEs	4	4	6	30	70	1	
PTEs per year (millions)	20.20	3.99	3.59	1.13	2.27	0.02	**31.21**

[a] Average tire life is 43,000 miles.
[b] Assumes Medium and Heavy tires were retreaded twice.
[c] Average tire life is 86,000.
[d] Values may not total exactly due to rounding.

Notes:
Number of tires per vehicle based on a load of 4,000 pounds per tire.
Light vehicle: gross vehicle weight (GVW) of 0 to 6,000 pounds
Medium light vehicle: GVW of 6,001 to 10,000 pounds.
Medium vehicle: GVW of 10,001 to 33,000 pounds.
Heavy vehicle: GVW of 33,001 pounds or more.
Sources: *California Motor Vehicle Stock, Travel and Fuel Forecast*, 1999; Norberg, 2002; Liu, 2001.

Method 3

The third method used in the analysis assumes a unit rate of 0.915 tires generated per person per year, as used by CIWMB (*Waste Tire Management Program: 2000 Annuaf Report*, 2001, p. 6). In order to project future waste tire generation in California, the CIWMB unit rate was multiplied by California population estimates supplied by the DOF. The number of tires diverted to manufacture crumb rubber products was also estimated by using a 10 percent growth rate in crumb rubber production from 1999–2000 data (*Waste Tire Management Program: 2000 Annual Report,* 2001, p. 6), and then applying this rate to each subsequent year.

Results

Estimates of waste tire generation are reported in Tables 42 through 44. Data in Table 42 show the results based on the use of the conversion factor reported by RMA. Table 43 presents the results of using Method 3, as well as an estimate for crumb rubber processing capacity based on earlier CIWMB findings (*Waste Tire Management Program, 2000 Annual Report*, 2001). The results of the tire generation analysis are compared in Table 44. Generally, the results of the different methods are within approximately 15 percent. The results of the analysis do not account for discarded vehicle tires used in mining, agriculture, and other heavy equipment applications. However, the number of tires used annually for these purposes represents a relatively small percentage of the total waste tire generation.

Table 42. Projection of California's Waste Tire Generation Using Method 1 and Estimate of Potential Supply of Tire-Derived Steel and Fiber Assuming 100 Percent Recovery

Year	Population (millions)	Tires (PTEs, millions)	Potentially Recoverable Steel (tons)	Potentially Recoverable Fiber (tons)
1997	33.20	33.20	58,100	36,520
1998	33.80	33.80	59,150	37,180
1999	34.00	34.00	59,500	37,400
2000	34.50	34.50	60,375	37,950
2001	34.76	34.76	60,827	38,234
2002	35.12	35.12	61,453	38,628
2003	35.89	35.89	62,805	39,477
2004	36.68	36.68	64,187	40,346
2005	37.47	37.47	65,579	41,221
2006	38.03	38.03	66,555	41,834
2007	38.59	38.59	67,531	42,448

Sources: *Waste Tire Management Program, 2000 Annual Report*, 2001; “Interim County Population Projections,” 2001, p. 4.

Table 43. Projection of Waste Tires Generated in California Using Method 3 and Estimate of Supply of Tire-Derived Steel and Fiber Assuming 100 Percent Recovery

			Crumb Rubber Production Only		
Year	California Population (millions)	Waste Tires Generated (PTEs, millions)	Tires Diverted (PTEs, millions)	Potentially Recoverable Steel (tons)	Potentially Recoverable Fiber (tons)
1990	29.5	27.0			
1991	30.1	27.5			
1992	30.7	28.1			
1993	31.1	28.5			
1994	31.7	29.0			
1995	32.3	29.6			
1996	32.6	29.8			
1997	33.2	30.4			
1998	33.8	30.9			
1999	34.0	31.1	6	10,500	6,600
2000	34.5	31.6	7	11,550	7,260
2001	34.8	31.8	7	12,705	7,986
2002	35.1	32.1	8	13,983	8,789
2003	35.9	32.8	9	15,365	9,658
2004	36.7	33.6	10	16,905	10,626
2005	37.5	34.3	11	18,603	11,693
2006	38.1	34.9	12	20,458	12,859
2007	38.6	35.3	13	22,505	14,146

Sources: *Waste Tire Management Program, 2000 Annual Report*;for population and waste tires generated data through year 2000

Table 44. Summary of Estimates of the Waste Tire Supply (in PTEs) in California, Methods 1, 2, and 3 (millions)

Year	Method 1	Method 2	Method 3
1997	33.2		30.4
1998	33.8	26.1	30.9
1999	34.0	26.9	31.1
2000	34.5	28.4	31.6
2001	34.8	29.1	31.8
2002	35.1	30.5	32.1
2003	35.9	31.2	32.8
2004	36.7	32.1	33.6
2005	37.5	32.9	34.3
2006	38.1	33.7	34.9
2007	38.6	34.3	35.3

The data in Table 45 show the values for VMTs employed in Method 2 and were taken directly from information available from Caltrans (*California Motor Vehicle Stock, Travel and Fuel Forecast*, 1999). The generation data presented in Table 46 were calculated using Method 2 and reflect estimated generation through the year 2007.

Table 45. Average Vehicle Miles Traveled (VMT) by Class (billions)[a]

Class	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Auto	205.996	213.254	217.149	222.509	227.752	232.523	236.952	241.194	244.971	249.319
Light vehicle	42.767	42.117	42.906	43.905	44.896	45.748	46.613	47.458	48.22	49.092
Medium-light vehicle	24.907	24.625	25.752	26.831	27.878	28.855	29.789	30.658	31.413	32.182
Medium vehicle	8.74	8.814	9.056	9.274	9.496	9.674	9.842	9.999	10.151	10.323
Heavy vehicle	7.267	7.511	7.795	8.046	8.304	8.527	8.743	8.947	9.144	9.358
Motor-cycle	0.804	0.845	0.848	0.848	0.849	0.85	0.851	0.852	0.853	0.854

[a] Used in Method 2 analysis.
Source: "California Motor Vehicle Stock, Travel and Fuel Forecast, 1999.

Table 46. Estimated PTEs Generated per Year in California Using Method 2 (millions)

Class	2001	2002	2003	2004	2005	2006	2007
Auto	19.1624	19.8376	20.1999	20.6985	21.1862	21.6300	22.0420
Light	3.9783	3.9179	3.9913	4.0842	4.1764	4.2556	4.3361
Medium light	3.4754	3.4360	3.5933	3.7439	3.8900	4.0263	4.1566
Medium	1.0925	1.1018	1.1320	1.1593	1.1870	1.2093	1.2303
Heavy	2.1195	2.1907	2.2735	2.3468	2.4220	2.4870	2.5500
Motorcycle	0.0187	0.0197	0.0197	0.0197	0.0197	0.0198	0.0198
Totals	**29.85**	**30.50**	**31.21**	**32.05**	**32.88**	**33.63**	**34.33**

Sources: *California Motor Vehicle Stock, Travel and Fuel Forecast*, 1999; Norberg, 2002; Liu, 2001.

CIWMB estimated that approximately 7 million PTEs in the year 2000 (*Waste Tire Management Program, 2000 Annual Report*, 2001) were diverted to crumb rubber production in California. Nine survey processors returned surveys identifying themselves as California crumb rubber producers. Of these, four reported estimated throughput based on an average 8-hour shift. Annualizing the production rate, the total estimated processing capacity of the four respondents is approximately 3 million PTEs per year. Assuming that the four respondents are average volume processors, the total processing capacity in California in the year 2002 is estimated to be approximately 6.1 million PTEs per year. This estimate is slightly less than the 7 million PTEs estimate by CIWMB for the year 2000.

The analysis of waste tire generation is the basis for estimating the potential supply of tire-derived steel and fiber. The maximum potential supply of steel and fiber would be that recovered if all waste tires generated had been processed for recovery of by-products. Under that condition, the quantities of recovered steel and fiber in 2002 is estimated under Method 2 to be approximately 61,000 tons and 39,000 tons, respectively, assuming 100 percent recovery of the by-products. Table 42 includes the estimated quantities.

Assuming crumb rubber production estimates for 2002 and 100 percent recovery of by-products, the potential annual supply of steel and fiber in 2002 under Method 3 is estimated to be approximately 14,000 tons and 9,000 tons, respectively. Table 43 shows the estimated quantities. Thus, the range of the potential supply of recoverable steel and fiber in 2002 could have been in the range of 14,000 to 61,000 tons and 9,000 to 39,000 tons, respectively. The Demand section of this report discusses supply levels further.

To improve the accuracy of values presented in previous sections of this report, better recordkeeping and/or product tracking must be employed. National tire sales data are available, but disposal facilities and/or processing facilities could increase the accuracy of production estimates by collecting data on, and providing reports regarding, resale, retreaded tires, and crumb rubber. Many states have implemented regulations requiring transporters, processors, and operators of final disposal sites to obtain permits. The State of California initiated a recordkeeping program on July 1, 2003 to determine the number of used/waste tires generated, transported, and delivered disposed. The Waste Tire Manifest System is designed to collect information on every transfer of waste tires in California.

Demand

This section discusses commercial uses for steel and fiber by-products recovered from tire processing in California and presents a perspective based on conditions in the rest of the United States and in the international marketplace. Market segments for the steel and fiber by-products are broken down by size, opportunity, and barriers to growth. Because prices in steel scrap markets differ significantly by region and scrap category, these market segments are covered as well.

Identification of Products or Potential Product Applications

The CalRecovery project team identified new and existing products for steel and fiber as a result of a literature search, an industry survey, and discussions with many experienced individuals representing processors and end-use markets and possessing knowledge of the characteristics of tire-derived by-products. Based upon all of the industry contacts, only one steel and four fiber commercial applications were found that used tire-derived materials. The number of firms actively participating in the waste tire by-product marketplace is a small fraction of the more than 800 firms contacted in the processor and end-use groups. Among the 206 responding to the survey from the processors group, fewer than 15 percent reported that they separated and recycled steel and fewer than 3 percent reported separating and recycling fiber.

Steel and fiber recovered from processing waste tires have more limitations than do other types of scrap, such as traditional forms of steel scrap or single-resin fibers waste. This has prevented broader acceptance by the marketplace.

Steel

Tire-derived steel has only a single current commercial use—scrap steel in making new iron or steel. Other potential end uses discussed below are steel-reinforced concrete and low-end wire applications.

Scrap Steel for Mills and Foundries: Scrap steel is a major raw material for new iron and steel production. More than 70 million metric tons of iron and steel scrap of all types were available for U.S. consumption in 2002,[3] compared with steel production of 92 million metric tons and pig iron production of 39 million metric tons ("Iron and Steel" and "Iron and Scrap Steel", 2003, pp. 88–89).

The amount of scrap steel employed varies with the type of steel-making process and the desired specifications of the final products. Electric arc furnaces converted 75 percent of steel scrap in the United States in 2002 and accounted for 51 percent of the nation's total steel production. Electric arc furnaces can be fed with charges of up to 100 percent scrap steel, whereas foundries using cupola furnaces to make cast iron might require slightly less than 50 percent scrap. High-specification iron or steel-making operations may require that no scrap be used. Table 47 sets forth the available market for merchant iron and steel scrap (that is, from sources outside of the consuming company's family transfers—in other words, just the receipts for materials received from brokers, dealers, or other outside sources). The table shows that more than 83 percent of outside receipts of iron and steel scrap were made by integrated pig iron, raw steel, and casting manufacturers. Iron foundries and miscellaneous users accounted for another 14 percent.

Table 47. 2001 U.S. Consumer Receipts of Steel Scrap From Outside Sources

Manufacturers	Million Metric Tons	Percent
Pig iron, raw steel, and castings	43.0	83.2
Steel castings	1.5	2.9
Iron foundries and miscellaneous users	7.2	13.9
Totals	**51.7**	**100.0**

Source: "Iron and Scrap Steel," 2001.

California manufacturers receive less than 2½ percent of U.S. iron and steel scrap.[4] Instead, California plays a much larger role in the foreign trade of iron and steel scrap. Shipments of domestic exports in 2002 from the state's departure points accounted for slightly less than one-third of all domestic iron and steel scrap exports (32 percent of 9 million metric tons) ("Ferrous Waste and Scrap, Ingots of Iron and Steel," 2002). General imports to California cities of iron and steel scrap were less than 1 percent of 2002 total in the United States ("Ferrous Waste and Scrap, Ingots of Iron or Steel," 2002).

There are literally hundreds of scrap iron and steel grades and classifications ("Guidelines for Ferrous Scrap: FS-2003," 2003), covering metallurgy (carbon and alloy types), sources (such as structural shapes, railroad rails, auto bodies, or engines), quality or contamination levels, and forms of the materials by size, shape, and density. To meet specific iron or steel requirements, operators carefully purchase to their individual specification, check each load versus the

[3] The U.S. Geological Survey's 2001 *Mineral Yearbook* chapter on iron and steel scrap, the December 2002 *Mineral Industry Surveys for Iron and Steel Scrap*, and the January 2003 *Mineral Commodity Summaries* are the sources for many of the statistics of this section. Steel producers had over 56 million metric tons of steel scrap available for consumption. Foundries and other steel operations added 14 million metric tons of iron and steel scrap available for consumption. Iron scrap was about only 8 percent of the total.

[4] The U.S. Geological Survey's 2001 *Mineral Yearbook* chapter on iron and steel scrap is the source that indicates that California, Oregon, and Washington collectively accounted for less than 5 percent of the U.S. receipts of scrap for consumption. Based on a West Coast steel scrap dealer estimate, California accounts for about half of this demand.

specification (and may reject loads), and blend scrap and other raw materials as needed in batch charges to their furnaces.

Despite the variety of materials that makes up U.S. receipts of steel scrap from outside sources (see Table 48), carbon steel scrap dominates, at more than 90 percent.

Table 48. U.S. Consumption of Scrap Iron and Steel From Receipts From Outside Sources[5]

Scrap Category	Thousand Metric Tons	Percent
Carbon Steel		
• Low-phosphorus plate and punchings	1,400	2.7
• Cut structural steel plate	5,400	10.5
• No. 1 heavy melting steel	5,300	10.3
• No. 2 heavy melting steel	5,300	10.3
• No. 1 and electric furnace bundles	5,400	10.5
• No. 2 and all other bundles	990	1.9
• Electric furnace 1 foot and under (not bundles)	160	0.3
• Railroad rails	390	0.8
• Turnings and borings	2,200	4.3
• Slag scrap	780	1.5
• Shredded and fragmentized	11,000	21.3
• No. 1 bushelings	5,900	11.4
• Postconsumer steel cans	220	0.4
• Other carbon steel scrap	2,300	4.5
Total Carbon Steel	**46,740**	**90.5**
Stainless steel scrap	1,200	2.3
Alloy steel scrap	340	0.7
Ingot mold and stool scrap	83	0.2
Machinery and cupola cast iron	840	1.6
Cast iron borings	420	0.8
Motor blocks	280	0.5
Other iron scrap	550	1.1
Other mixed scrap	1,200	2.3
Totals	**51,653**	**100.0**

Source: "Iron and Scrap Steel," 2001.

[5] Data exclude companies not reporting and data withheld to avoid disclosures. Thus, the information gives an approximation of the relative size of scrap classifications.

Only a small percentage of iron and steel scrap categories are similar to tire-derived steel, as most iron or steel scrap is bulkier and denser or more specialized. The bronze (copper and tin) or brass (copper and zinc) coatings of tire-derived steel further set it apart from other carbon steels. Some contacts compared tire-derived steel, if bundled, with No. 2 or No. 3 bundles, which account for less than 2 percent of the market. A few steel makers compared tire-derived steel to post-consumer steel cans, which make up less than ½ percent of the steel scrap market. Turnings and borings, at more than 4 percent of the market, can be close in particle size to tire-derived steel pieces and may have acceptance problems similar to those for tire-derived steel, such as springiness, a tendency to tangling, and contamination with hydrocarbons. Certainly, given the breadth of the scrap market, a cleaner and denser tire-derived steel could compete with a number of classes of steel scraps.

The largest category of steel scrap, with a more than 20 percent share, is shredded and fragmentized steel. Tire-derived steel is generally shredded or fragmentized. However, most of the materials grouped in this classification are much denser and larger in fragment size than tire-derived steel. Most pieces of steel from auto bodies and other materials in the shredded and fragmentized class are bulky—in 2- to 3-inch particles, rather than wire-like pieces. Bulk weight and size, considerably exceeding that of tire-derived steel, are necessary in the furnace charge to prevent losses. The Task 2 survey found an example of a reported blending of tire-derived steel with shredded car bodies. Nevertheless, tire-derived steel makes up only a small part of this classification.

As now processed, the steel from waste tires is usually an inconsistent low-quality material that gains wider acceptance in the scrap steel markets only during periods of high demand, losing market share when the market is oversupplied. Moreover, tire-derived steel's rubber content, low density, difficulty in being compacted, and alloy coating make the steel fraction unsuitable for many applications.[6] Another drawback is the scrap's lack of uniformity, which can vary from shipment to shipment in regard to rubber content, source of steel (bead, body, or belt wire and mixtures), alloying (bronze or brass), and form (chopped, shredded), and compression level (loose, compacted, or briquette)).

However, for applications such as fluxing agents for smelters that want copper in the melt bath, the copper-based coating on tire-derived steel is an advantage. Tire-derived steel is also used in less demanding, wide-specification steel applications such as rebar and selected pipe grades. Market acceptance will improve if the scrap's rubber content falls from 10 percent to under 1 percent and if compacted or baled to 70 to 80 pounds per cubic foot, more than twice that of loose wire.

Depending on the process, tire-derived steel wires may be shortened as a result of repeated reprocessing to reduce rubber content. As the wire length gets shorter, packing density increases. For example, as the product length falls from 2 to 4 inches to under ½ inch, its density increases enough to meet some density specifications. However, because the scrap is still in loose form, most scrap consumers are not interested in it because of the processing losses associated with the small individual particles and because the transferring, shipping, and feeding requirements to use it are more resource-intensive compared to heavier steel scrap.

[6] While there are literally hundreds of scrap steel classifications and grades, tire-derived steel does not fit into any existing categories because of the combination of attached rubber, low density before compaction or bundling, and alloy coating. Recently (May 2003), ISRI issued standards specifically for tire-derived steel.

Some scrap dealers and customers do take loose tire wire. Their purpose is to blend the material with other steel scrap or compact it to meet users' product specifications, environmental limits, and other operating considerations.

A few processors (11 percent in the Task 2 survey, with at least three in California) can separate bead wire. Bead wire is not a solid wire. It is composed of many loops of single wire strands fastened together. However, in many ways, it functions as if it were a single unit. Bead wire, which is separated by pulling it from each side of the tire, has the approximate dimension and shape of the inside circumference of the tire. If the starter section is cut off, bead steel recovery is clean, with less than 1 percent rubber. In a passenger tire, bead wire weighs up to one pound and has a bronze coating. The steel used to make bead wire can range all the way from low-grade to high-grade (that is, 70 to 80 grade) carbon steel. In the latter case, the steel is the same as that used to fabricate high-tensile-strength belt wire. Bead wire is frequently sold after being cut into 2- to 6-inch lengths, and bundled or compacted. However, since bead steel is resilient, it is difficult to compact. (Refer to Chapter 2 for a detailed description of the differences in tire-derived steel.)

If bead wire is not pulled separately from the tire, it is recovered along with body or belt wires. Some processors refer to the smaller gauge wire used in the belt and body as "fines" when separated in the recovered form. The mix of tire steel when collected has the appearance of coarse steel wool. The body and belt wire has a brass coating for better adhesion to the rubber. If the tire is first shredded into small pieces, followed by ambient grinding to recover crumb rubber, the steel wire is cut to variable lengths that average about 1½ inches. The wire pieces from the processing are crimped. The cryogenic recovery process, which achieves separation by freezing the tire and then using a hammermill to break the materials apart, may offer a cleaner separation of rubber, steel, and fiber in some operations than ambient processes. Processing equipment, operational skill, final product objectives, and separation methods, as well as process type, determine the final by-product quality.

Tire-derived steel from tires is a much different product from the home scrap[7] steel produced by tire manufacturers. Manufacturers' home scrap is cleaner and more uniform, and it is typically sold into the scrap market as a continuous fabricated wire on a reel. Because of its configuration, it can be used directly in wide-specification wire applications.

Steel Fiber-Reinforced Concrete: To reduce concrete cracking in tunnels, bridges, walls, slabs, and other applications, a separate wire fiber, or one used in conjunction with rebar, is introduced into the concrete. Table 49 presents key characteristics of the steel fiber-reinforced concrete market, such as a uniform length of typically 1 to 3 inches and no rubber or rust.

Some concrete reinforcing applications require specific steel types such as stainless steel, specified by a design engineer or purchasing entity, whereas others have less rigorous specifications. Virgin or home-scrap carbon-steel wire is used in this market. The total of all steel used in this form of concrete reinforcing was estimated by a supplier at 450,000 metric tons annually. If the steel used includes rust, dirt, or other contaminates such as rubber, instead of reinforcing the concrete, it acts as a source of crack propagation. Steel from tires was tried in the past in this application, but proved unsuccessful because of contamination. Indeed, no Task 2 survey respondent referred to concrete reinforcement as an existing or potential market for tire-derived steel, and thus it is assumed that steel from tires is not being used. If quality issues are

[7] Home scrap for a specific material includes surplus, obsolete, scrap, or waste materials produced during the manufacturing of products within a specific facility, as well as the same specification materials available unused from consumers or distribution channels.

overcome, the successful introduction of steel from tires into concrete reinforcing applications, and resulting market growth, will be slow, occurring only after case-by-case qualification and acceptance.

Table 49. Market Characteristics for Steel Fiber-Reinforced Concrete

Material Specifications	Greater than 1 inch, up to 3 inches in length. Typical length is 1½ to 2 inches. Stainless steel inhibits rusting; carbon steel and home scrap are used as well. The steel can contain no rubber. Crimping helps. Steel fiber loading can range from a few tenths of a percent to 2 percent.
Considerations/Problems	The steel needs to be demonstrated, qualified, and specified. If tire wire tends to ball or clump, it is unacceptable. Its variable length and tendency to shorter lengths are also issues.
2002 Price	New wire without rubber and of uniform specification length sells for $0.15 to $0.20 per pound. Rust-free waste tire wire, which would have some rubber, could cost no more than $0.10 to $0.20 per pound.
Demand, All Materials	The annual U.S. market for all steel fiber is $200 million, or approximately 1 billion pounds (450 thousand metric tons). The European market is larger.

At least 15 states are testing or have tested steel and other fibers in concrete roadways (Federal Highway Authority, 2000). Caltrans has not specified the use of steel fibers, and the principal Caltrans concrete engineer indicated that he believes the use of steel fiber of any kind has not yet been proven to offer a benefit (Pile, 2003). No specification for steel fiber use was found at the county level in California for roads and related structures, and the use of steel fibers, if any, remains undetermined. Steel fibers are more commonly used in large slabs. Tire-derived steel will not be used in this application until it is essentially or completely rubber-free. Given that little chance exists in the next five years of achieving a rubber-free tire-derived steel, no market is foreseen on the immediate horizon.

Low-End Wire Applications: Home-scrap tire wire is sold to makers of wire brushes, clothesline wire, and wire clothes hangers. Although CalRecovery did not speak directly with these groups of manufacturers, several contacts during the survey process indicated that the manufacturers require wire on reels. Therefore, it was assumed that tire-derived wire has no potential in these applications. Even if loose wire cuttings were an acceptable raw material for these end uses, the rubber that adheres to tire-derived steel wire would certainly rule out most applications where the wire is exposed (for example, brushes). Nor does crimped, loose, short, and variable-length tire wire appear to be a good match for clothesline wire or wire clothes hanger manufacture. Thus, until an acceptable low-valued wire product is identified, tire-derived steel is assumed to have no potential in these wire markets.

Survey results show that 11 California companies reported that their primary business activity is brush manufacture, and 57 make wire products, forms, or ties. Some of these firms may be able to use tire-derived steel. A more detailed opportunity analysis could identify additional wire applications that might use tire-derived steel. The analysis could also clarify whether the use of tire-derived steel would require changes in the end-use manufacturing process, introduce material losses, or would result in other liabilities that might effectively bar its entry.

Fiber

Tire-derived fiber markets are even less well developed than those for steel. Only a few processors reported in the Task 2 survey that they were selling fiber commercially, other than as TDF, which is the most substantial application for fiber. Current markets for fiber are localized and have resulted from specific, opportunistic situations that afford an economic transport radius and flexibility in quality requirements. Nor have these few examples generally transferred successfully to other market locations. Instead, processors are typically pleased to simply avoid disposal costs by giving the fiber away or even paying the user a "tipping" fee and/or delivery cost. As a result of these circumstances, many processors have given up on fiber market development.

Thus, non-TDF fiber sales have no uniform domestic or international markets or consistent niche markets, and fiber's penetration is very low in any market in which it participates. Nor are there industry standards for tire-derived fiber that could help create a broader market. No company or organization was identified as working to establish industry-wide specifications for tire-derived fiber, as ISRI has done recently in the case of tire-derived steel.

Only a few actual applications were reported for tire-derived fiber, and the number of processors involved was quite limited. Nonetheless, processors are seeking opportunities for tire-derived fiber and have many ideas about possible applications. These new market end uses will depend on post-consumer requirements for mixed fiber.[8]

The 18 possible non-fuel end uses identified in the Task 2 survey have been merged into nine application types. Processors identified only four non-fuel uses:

1. Reinforcing additive for rubber, plastics, or composites.
2. Concrete additive.
3. Sound deadener.
4. Stuffing material, as either current or past commercial applications. Reasoning that low-valued tire-derived fiber might be a possible substitute, respondents also indicated 5 non-fuel end uses as possible avenues for growth. All would compete with current applications for virgin or home-waste polyester, nylon, or mixed fibers.

Fiber TDF: Fiber TDF is the largest current market for tire-derived fiber. Processors that make TDF are well positioned to also sell fiber TDF because it competes with or supplements rubber-based TDF. This synergy is a substantial benefit because, as noted below, most processors would otherwise have to pay disposal costs for the fiber. In addition to competing with rubber-based TDF, fiber TDF competes with conventional fuels such as natural gas, oil, and coal.

Of the more than 300 companies in the processors group contacted, only about 5 percent sell fiber TDF for fuel applications.[9] Most of these companies also produce chopped or shredded tire TDF. The processors' returns on sales for fiber TDF ranged from positive—for prices just below alternative fuel value—to negative—giving the material away and paying freight to avoid

[8] Using present methods, mechanical separation of tire-derived fiber into specific resin types is not considered economically practical. Recovery of single-resin tire cord materials might be achieved by processing only a uniform group of tires (those that have the same type of fiber construction). However, the difficulty and cost in collecting and segregating tires of standard type probably makes this approach impractical in most situations.

[9] One California processor reported selling fiber for a fiber TDF application.

disposal costs. Processors that make TDF or engage in civil engineering applications for tires, such as landfill cover or containment systems, use processes that on average generate less than a quarter of the fiber recovered from crumb rubber production.

As described in the Task 2 report (survey), fiber as a heat source has a potential BTU value in the same range as rubber TDF and essentially no sulfur. However, its water content may reduce its effective BTU value, and in either loose or baled forms, it may not be compatible with customers' feed delivery systems.

A comparison table of supply-and-demand for fiber TDF was not developed in order to concentrate on non-fiber applications that fall more within the focus of this study. The paths to commercializing fiber TDF will be similar to those for rubber TDF.

Reinforcing Additive for Rubber, Plastic, and Composite Materials: The use of polyester or nylon to reinforce rubber, plastic, and their composites currently account for only a very small fraction of the overall markets for final products made from rubber or plastics. Experts in the field indicate that adding fiber to rubber creates voids and weakens the end product rather than (as might be expected) adding tear resistance, reducing tear propagation, or imparting other beneficial characteristics. Similarly, with reinforced plastics, the uses of polyester and nylon fiber are limited because most resin systems employ thermoset polymers, with fibers such as glass, Kevlar® (aromatic polyamid), and carbon accounting for almost all of the applications. Polyester is a thermoplastic resin that is less compatible in systems employing thermosets. Nonetheless, minor amounts of polyester and nylon are used in applications that employ long-filament fiber. No uses of short-length single fibers were identified for the polymer reinforcement market. Therefore, the tire-derived fiber market is likely to remain stalled until commercial outlets for fiber with characteristics of tire-derived fiber are discovered.

Investigation showed that in a few isolated situations, fibers are added to rubber and plastic applications. In 1997, NRI Industries, the largest mud flap maker in North America, started a Canadian plant that makes rubber mat products such as mud flaps, air dams, trailer covers, flooring, and underlay. Although the amount of tire-derived fiber varies among the applications, many use a significant amount. The starting materials are waste tires or tire sections such as tread or sidewalls. The resulting crumb rubber needs to be steel-free for NRI's manufacturing process. NRI is reported to be the only manufacturer of rubber products that adds fibers to its products. NRI continues to develop new products for the auto industry and elsewhere, and has the resources to develop new rubber products using tire-derived fiber additives. NRI ships its products to the United States and other countries from Canada.

ReSyk, Inc., based in Salt Lake City, has developed a molding system that uses plastics, rubber, fiber, and natural materials to make molded products. ReSyk sells the molding equipment that tire processors might use to convert waste materials from their operations (for example, fibers, rubber, and metal fines). The process handles contamination such as dirt and oil. It can also make final products that could replace products based on wood, metal, and reinforced plastics. Fiber and other materials serve as filler and add rigidity to the final product. Although this potential opportunity for tire-derived fiber is an interesting one, it is far from guaranteed. It is not clear that a final molded product, using tire-derived fiber, would have the attributes required by the market or a cost structure that would be viable.

Fiber companies have been supporting carpet recycling to achieve recycling of resin. More recent development activities incorporate single-resin fiber waste in applications such as paneling cores and wallboard backing, and as additives for recycled products such as railroad ties manufactured from plastic or rubber. The focus is to reduce waste in the product chain. If successful, these single resin fiber applications could open the market to the use of mixed-fiber materials, such as tire-derived fiber.

Concrete Additive: Synthetic fibers are added to concrete for reinforcing purposes. At least two processors are selling tire-derived fiber for this purpose, and others have successfully participated in the past. The Task 2 survey respondents mentioned that one of the benefits that fiber confers is sound deadening. However, they also indicated that fiber length is a major commercial hurdle. Processors did not indicate that the fiber coating added for rubber adhesion was a limitation in concrete. Table 50 presents market characteristics for concrete that is reinforced with synthetic fiber and that calls for fibers other than polyester.

Table 50. Market Characteristics of Concrete Reinforced with Synthetic Fiber

Material Specifications	Polypropylene and nylon (nylon's absorption of water can be both a positive and negative factor, depending on technical requirements). Homopolymer, no color, and no crimping are specified. Ninety percent of market is for material ¾ inch long. Polyester may not be acceptable because it has an alkaline reaction problem with the concrete mix.
Considerations/Problems	The presence of adhesion coatings on tire-derived fiber may be unacceptable. Tire-fiber retains water on exposure to the processing conditions at most processors. Baling helps minimize the potential problem. Variable-length fiber, which typically averages less than ½ inch in length, may be too short. Crimping, although stated to be a problem by one supplier, in fact is thought likely to improve the integrity of the concrete.
2002 Price	$1.00 per pound for polypropylene.
Demand	Sources in industry estimate the total fiber market in reinforcing of concrete at 20 to 50 million pounds per year.

Conversations with suppliers of fiber for concrete reinforcing indicated an unclear prospect for tire-derived fiber in these applications, given that single-resin polyester is not the fiber of choice. Tire-derived fiber's low cost is thus the most likely reason for its being blended or used in place of other fibers in low-performance applications. Fiber reinforcement used in most concrete projects is likely to be specified, qualified, and tested. To prove the efficacy of tire-derived fiber as reinforcing material would likely entail a long effort and one with an uncertain outcome.

Although associated factors clearly reduce the prospects for the use of tire-derived fiber in concrete reinforcement, the fact some tire-derived fiber is being sold in small amounts offers the possibility of developing niche markets for it.

Soil Amendment/Mulch/Erosion Control: Very few in the tire recycling industry view soil amendment, mulch, and erosion control as commercial outlets for tire-derived fibers. Although recycled rubber has been successfully promoted for soil and mulch applications, no fiber is being reintroduced to crumb rubber products for this market. In the Midwest, tire-derived fiber was reported to be used in an architectural landscaping project, and mats of single-resin polyester and other natural and synthetic fibers are being used elsewhere for hillside, riverbed, and shoreline projects, railroad track beds, and other erosion-control projects. Erosion control is a $13 billion market with a wide variety of applications, and with most emphasis now on soil lost as a result of cultivation practices. Federal and state programs have been funded to demonstrate that cotton gin wastes are a positive benefit as a soil amendment. It is possible that tire-derived fiber might be able to use this research to support its development in similar applications.

Several companies use fibers in erosion control. One company has developed a recycled polyester fiber mat with filament lengths of 5 inches for stabilizing riverbeds and hillsides. A second company sells hydrospray technology systems that include a 1¼-inch polyester fiber for hillside erosion control in an overseeding application. Another firm offers a specialty fabricated polypropylene fiber system, which is sprayed in place and rototilled to improve drainage and root development on footpaths (preferred fiber length of 2 to 3 inches). Fiber length is important in these applications. If too short, it does not provide the intended soil conditioning or control. If too long, it tends to be caught in the spray nozzles or other application equipment. Rubber adhering to fiber can clog equipment.

Geotextile applications consume more than 25 million pounds annually of polyester. Their principal use is in applications that provide reinforcement and stabilization in erosion control. The typical form is a needle-punched mat. Polyester fibers or mixed fibers sometimes compete in the international market for a broader set of erosion control or amendment systems because of an emphasis on low-cost materials. As in other applications, rubber contained in the fiber could be an issue for needle-punched applications causing manufacturing downtime. The study team was not able to identify any studies on the effectiveness of tire-derived fibers in soil amendment or erosion control applications.

Packaging or Blanketing Material: Survey comments and other suggestions by industry contacts indicate that tire-derived fibers have been used in animal blankets and protective covers for moving furniture. The loose tire-derived fiber would receive greater consideration for such applications if processors could eliminate the metal. However, liabilities associated with injuries from entrapped steel slivers essentially preclude all uses in which humans, livestock, or pets might be harmed. A tire-derived fiber similar to cotton batting might find a packaging application, provided the liability issue could be surmounted.

Assuring the purity of tire-derived fiber is also an issue. For sealing, needle punching, and other joining methods used for forming mats and blankets, the presence of rubber or metal in fiber can cause problems. In fiber heat-joining techniques, if the contained rubber is not uniformly distributed, it may show up as patches that change the character of the mat and its appearance. With needle punching, staple fibers are “sewn” together. If a needle in a high-speed line hits a rubber particle, the needle may break, with ensuing production line downtime. Finally, unless tire-derived fiber can be guaranteed to be metal-free, no significant market will develop in packaging or blanketing materials.

Sound Deadening, Filtering Media, Stuffing, Fillers, and Insulation: Sound deadening, filtering media, stuffing, fillers, and insulation applications employ polyester and nylon home waste, along with virgin fiberfill and non-woven filament. The virgin filaments used are frequently tailored specifically for the application (for example, with random patterns in the non-woven matrix, “feather” characteristics for sleeping bag and pillow fill, cavities in the filament to add insulating properties). Home waste that derives from the fiber manufacturing lines with specialized properties obviously has a major advantage over other waste- or tire-derived fiber for reuse in the applications that benefit from or require tailored fibers.

Although the total market for waste polyester exceeds 100 million pounds per year in the United States, most markets such as retail stuffing for hobbies and sewing projects, rope, or reuse in primary applications are not suitable for tire-derived fiber. The tire-derived fiber’s short length, lack of purity, steel inclusions, and other quality issues preclude many potential applications.

As a rule, waste fiber dealers will not consider waste fibers unless they are of a single-resin type; a single grade within the single-resin fiber type is better still. Home-waste tire cord at a level of about 2 million pounds per year is being sold for applications such as sound deadening, filter media, and stuffing applications. Typically, not enough waste is available. Substitution for waste tire cord and other market opportunities based on the properties of a fiber mat might be available to a mixture such as tire-derived fiber. Before consideration, the tire-derived fiber has to be free of both rubber and metal. The fact that tire-derived fiber is usually dirty also imposes a hurdle.

Firewalls, interliners for automobile trunks, mattress-spring overlays, and inner padding for furniture could be possible applications for tire-derived fiber. However, metal and rubber contamination of current materials blocks consideration of these uses. Although tire-derived fibers do serve a few, isolated markets, such applications are unlikely to become significant until a sure method for eliminating metal is found.

Carpet Underlay: A variety of materials is used for the padding under carpets, with virgin and recycled polyurethane the largest volume materials. More than ½ billion pounds per year of virgin polyurethane is used. At the other end of the quality spectrum, felt, waste textiles (such as pile trim from carpet fiber), and waste fibers are also made into carpet padding. Tire-derived fiber has been tried unsuccessfully in this application due to the quality and contamination issues mentioned above. The presence of metal is unacceptable, and the presence of rubber can form uneven blotches when heated and break needles in needle-punch joining systems. Moreover, dealing with moisture buildup in the fiber adds to the manufacturing cost.

For carpet underlay, the fiber length must exceed ½ inch, with 2 to 3 inches meeting market needs best. If rubber could be evenly distributed in very small particles that would not break needles, some of the barriers to its use might be overcome.

Unfortunately, carpet underlay manufacturers have not forgotten the downtime associated with experiments using tire-derived fiber, and they will be extremely reluctant to test the fiber again, even if they can be assured that impurities have been removed.

The overall market for carpet underlay, where polyester and nylon waste fiber compete, exceeds 40 million pounds per year, but is declining. Although padding increases the life of carpet and is cost-justified, most consumer buying decisions are based on reducing initial investment, and padding is sometimes not purchased as a result. Unless tire-derived fiber can be made free of rubber and metal, there is little chance it will be used in this application.

Asphalt Additive: Fiber or fiber structures are added to asphalt systems to improve material integrity and flex strength. The market for asphalt has many segments and many different applications even within paving and the repair of it. Hot mixed asphalt surfacing provides the principal layers or surfaces of many roadways, airports, parking lots, and driveways as a wear coat, binder, or base course. In 2001, the United States used an estimated 572 million metric tons of asphalt, or almost double the European market. While direct addition of fiber to paving mixture has been tried, it is not widely practiced. Caltrans and others also question whether the addition of fibers to the asphalt pavement provides measurable improvements in road durability. In tests, fiber addition to the asphalt paving mix has not increased its effectiveness.

Porous asphalt uses polymers and sometimes fibers in a paving wear coat for strength and to bind stone and asphalt. Porous asphalt reduces traffic noise. France, The Netherlands, and Japan are significant users of this type of asphalt system.

Another asphalt, emulsion, is used for surface sealing. The United States uses more than 2 million metric tons annually of emulsion asphalt. Many systems are being used, including some that integrate synthetic fibers. Though not using it, Caltrans believes that road sealer with fibers at a right angle to the road offers the most protection to the road (Pile, 2003). The bulk of the fiber additions are cellulose and mineral at the rate of $^{3}/_{10}$ percent. France has used a chopped polyester fiber system to form a layer to prevent cracking (at 1 percent level). About 50 metric tons of polyester fibers were used in France in 1990.

Asphalt wear coats for rut control, called stone mastic, are used differently across the world. Where it is used, it can account for 3 percent to 10 percent of the total asphalt. Fibers are only sometimes used and, typically, they are natural fibers such as cellulose or mineral, again at an addition level of $^{3}/_{10}$ percent.

Repair or the first treatment for resurfacing applications will employ an asphalt crack sealer for $^{1}/_{8}$- to -to ¾-inch separations. One specification states that synthetic polyester fiber of 7 millimeters be used at the level of 6 percent to 7 percent in the asphalt sealer. Other specifications call for fibers, such as polypropylene and polyester, in lengths as short as 6 millimeters. Fiber additions are frequently not employed in crack sealers because the main attribute sought is adhesion to the existing asphalt that fiber does nothing to support.

Another fiber application, used in conjunction with asphalt, is geotextile woven and non-woven mats that are mainly polypropylene (some polyester used). For paving, the polypropylene volume is thought to be above 25 million pounds annually. One of the most successful applications employs a polypropylene layer sandwiched between two asphalt layers to dissipate cracking and keep the asphalt paving together. This fiber layer approach has been shown to lengthen road surface life. However, Caltrans does not use fiber layers because contractors cannot easily separate the polypropylene layer from asphalt during removal (Pile, 2003). After the useful life of the paving surface, the asphalt is stripped away and prepared for reuse. The presence of the polypropylene layer makes asphalt reuse less practical.

Synthetic fiber use in asphalt is at least a market of tens of millions of pounds. The polyester portion could be 5 million pounds annually. Asphalt seems a natural outlet for tire-derived fibers because the environmental containment provided by the asphalt should reduce the risk of any problems from rubber and metal contamination on the tire-derived fiber. However, none of the Task 2 survey respondents indicated that tire-derived fiber is being used for asphalt paving. During the supply and demand portion of the project, a call to the Rubber Pavement Association, which has many processors and tire recycling technology companies as members, indicated that no fiber was being used. Similarly, calls to other asphalt and paving associations, plus State and county officials, identified no clear market application for tire-derived fiber. Thus, while fiber addition to asphalt might potentially be a market opportunity, validating the market potential awaits testing of specific commercial applications.

California Demand

Before the supply-and-demand analysis was performed, it was unclear whether the tire-derived markets for steel and fiber are limited by supply or by demand. The Task 2 survey verified that a number of California processors were disposing of tire-derived steel and fiber. In addition, the Task 2 survey was not able to locate end users of tire-derived steel and fiber in California. It is also well documented that quality of supply can restrict steel and fiber sales. Taken at face value, the market appears demand-limited.

However, there are arguments for a supply limit as well. If individual processors are not within an economic radius of customers, they are effectively blocked from full participation in tire-derived steel and fiber markets. The volume from “uneconomic” locations is excluded from the marketplace. Several California processors make products that do not result in the production of fiber and steel, or they process only tires/tire sections with little fiber or steel. If processors use waste collection services (as many do), the recovered steel will be blended with other scrap steel, resulting in no differentiation between the recovered steel and other types. The presumption is that this tire-derived steel flows into the steel scrap market. However, waste haulers could simply dispose of it, effectively limiting supply.

To analyze demand in California for tire-derived steel and fiber, CalRecovery charted historic levels of production from processors that recycled rather than disposed of tire-derived by-products, determined the potential for recovery of tire-derived steel and fiber based upon the number of tires diverted by recycling and as TDF, and evaluated the California markets for tire-derived steel and fiber. Given the limited number of active processors, to assure confidentiality, neither sales nor volume information for individual processors is provided. Instead, the study team arrived at the supply amount by using the average tire-derived steel and fiber per tire by two different methods.

First, actual quantities were estimated for recovered tire-derived steel and fiber. For processors that reported on the Task 2 survey that they recycled steel and/or fiber, annual production of tire-derived steel and fiber was determined based on reported processing capacity and operating rates (Table 51). The second approach generated the potential supply using the CIWMB's estimates for tires consumed in the making of crumb rubber, other rubber products, and TDF for the period of 1990 to 2001 (*Waste Tire Management Program: 2000 Annual Report,* 2001) and study team estimates for 2002 and 2007. The potential supply of tire-derived steel and fiber assumes full recovery of all contained steel and fiber.

Table 51. Estimates of Recovered By-Products from Waste Tire Processing in California (1997 to 2007)

	PTEs (millions)		
	1997	**2002**	**2007**
Diverted Tires			
• Recycled rubber products	5.4	16	23.3
• All TDF sources, excludes TDF	9.0	5.2	6.2
• Totals (assumes full recovery)	14.4	21.2	29.5
Processor recovered steel and fiber by-products for sale[10]	1.3	5.8	6.7
	Pounds (millions)		
Estimated Potential Diversion			
• Tire-derived steel	19	37	57
• Tire-derived fiber	12	22	34
Production from Known Sources			
• Steel scrap	Under 1	Under 5	Under 15
• TDF fiber	No market	Under 1	Under 1

Potential full recovery for the production of tire-derived steel and fiber in California is driven by the production crumb rubber, rubber products from tires, and civil engineering and TDF applications. For the base case, growth in use of non-fuel recycled rubber products is 8 percent annually for the period from 2002 to 2007. For fuel products, it is 3½ percent annually (Table 52). The average 2002 to 2007 growth for non-fuel rubber products from waste tires (8 percent) is derived from a crumb rubber growth estimate of 10 percent annually and a forecast for the

[10] Forecast based upon only known plans for expansion and additional recovery.

remaining non-fuel products of 5 percent annually. To meet these forecasted growth levels, the percentage of diverted tires would have to approach 100 percent by the end of the period and remediation efforts of the CIWMB would need to continue producing, at least, 1.5 to 2 million PTEs annually.

Table 52. Estimated Growth Rates of By-Products from Waste Tire Processing in California Base Case Growth Rates (1997 to 2007)

Applications	Five-Year Average Annual Growth Rate (%)	
	1997-2002	2002-2007
Recycled rubber products	24	8
All TDF sources, except fiber	-14	3.5
Steel scrap	43	16
TDF fiber	no market	3.5

Production of products derived from non-fuel rubber grew rapidly, at more than 33 percent per year from 1990 to 2001. Both nationally and in California, non-fuel tire-derived rubber products have been growing at over 20 percent annually from 1999 to 2001. In California, TDF production increased quickly until 1995, but after that time, production and use dropped dramatically. Nationally, there was a dip in tire consumption for TDF in 2001. However, its 1999 to 2001 annual growth is still almost 10 percent. These past trends support the growth estimates for future tire-derived rubber products for non-fuel and fuel applications used in the base case.

Table 51 compares estimates of actual tire-derived steel and fiber by-product recovery to the estimated quantities of the steel and fiber contained in all tires diverted for recycling and fuel. The estimates for 2002 indicate that about 27 percent of the available steel and fiber was recovered from tires that were processed. While not all steel and fiber will be recovered, the current low level suggests demand is the main limitation. Even among processors who reported recycling, not all steel and certainly not all fiber is being recovered. Tire-derived steel and fiber are expected to experience significant continuing growth over the next five years, albeit from a very small base.

Using the production of known waste tire processors as an estimate of the size of the 2002 end use markets, the estimated generation is under 5 million pounds for tire-derived steel and under 1 million pounds for tire-derived fiber.

A number of forecast cases are possible, based on different assumptions about future growth for tire-derived steel and fiber markets. The range of possible forecasts varies from no growth to only a modest expansion. Focusing on tire-derived steel, the no-growth view has creditability because of its difficulty in achieving acceptance in traditional steel scrap markets. A somewhat higher growth comes from just maintaining its present market share and growing with the scrap steel market. In the United States, while some estimates for steel growth are as high as 4 percent annually for the next five years, the historic trend for steel and, therefore, scrap steel are growing at only an annual 1 percent for long-term growth and trough-to-peak rate of 2 percent to 3 percent annually. Using the assumption of either no growth or constant market share does not test the potential for tire-derived steel, since in either case the forecast is no different or only slightly higher after five years than the market volume in 2002.

Clearly, many processors desire better performance with steel and fiber by-products, and there are attempts by processors to promote greater acceptance of the by-products. Thus, it is reasonable to expect that gradual improvement in quality plus other steps, such as better marketing and packaging of tire-derived steel, will facilitate higher penetration of the steel scrap market. The base case presented in Table 52 assumes a 16 percent annual average growth rate for the period 2002 for tire-derived steel. This growth estimate represents a meaningful increase in tire-derived steel that allows the testing of its ability to penetrate the steel scrap market. The estimated production and use flows from the output of existing processors that recycle and reported plans for expansion. This base case annual growth rate is many times the expected rate of expansion of the California and U.S. steel scrap industry and would result in 2007 sales being double to triple those in California in 2002.

Table 52 presents a base case for future waste tire rubber production that carries forward the trends of the 1990 to 2001 period and the associated steel and fiber by-product output from processing tires. While the five-year average growth rate shows a substantial increase, the fully contained potential for tire-derived steel and fiber recovery is considerably higher. Tire-derived fiber consumption is effectively tied to rubber-base TDF and other fuel markets (see fiber section following the steel section immediately below).

If the market growth for recycled rubber holds as estimated and shown in Tables 51 and 52, both existing processors and new entrants would contribute to increasing production of tire-derived by-products in the California marketplace. Based on the Task 2 survey results, several processors are considering upgrading their product lines, thus increasing the potential sources of tire-derived steel and fiber. New entrants are likely to take advantage of new technologies that yield cleaner tire-derived steel and fiber. Supply will not be limiting to tire-derived steel consumption, as the potential full recovery of steel from tires being processed is almost four times the base case recovery in 2002. As market conditions improve for tire-derived steel, steel recovery will follow naturally.

New processor capacity could be needed in California because the ability of individual processors to reach the markets for tire-derived steel and fiber will continue to have limits due to such factors as distance to market and quality constraints.

Steel

The base case for recycled rubber products assumes a high production of marketable tire-derived by-products and a potential major increase in market penetration of tire-derived steel. However, there is considerable resistance from scrap steel dealers and end users due to the quality of tire-derived steel. Thus, in the next five years, realizing the expected growth for tire-derived steel will depend on the suppliers' ability to improve quality (reduced rubber content) and on some form of densification or bundling. Table 53 shows five markets for steel scrap that tire-derived steel can begin to penetrate. The penetration levels for the five categories are shown in order to investigate the viability of the base growth case for recycled rubber products. Penetration of the individual categories ranges from 1 percent to 5 percent, and would lead to an overall penetration rate of 0.5 percent of the total iron and steel scrap market of California. When the 0.5 percent penetration is applied to the state steel scrap market and the exports leaving California, an available tire-derived scrap market of above 40 million pounds annually results. A reduction in the already low-level California imports of scrap steel, which would be expected if tire-derived steel becomes more commercially common, is not anticipated to materially change the analyses.

Table 53. The Available California Markets for Tire-Derived Steel

Category	Total Scrap	Tire-Derived Steel	
	Percent Total Iron and Steel Scrap	Percent Penetration by Category	Percent Total Scrap
No. 2 and all other bundles	1.9	5	0.1
Turnings and borings	4.3	2.5	0.1
Shredded and fragmentized	21.3	1	0.2
Postconsumer steel cans	0.4	5	0.0
Other carbon steel scrap	4.5	1	0.1
Sum: Percent of each category of total scrap times the respective penetration rates			0.5
2002—California	**Metric Tons (thousands)**	**Pounds (millions)**	**Annual Potential Market (millions of pounds)**
Scrap receipts	1,150	2,535	12
Exports	2,839	6,259	30
Imports	ignored	no market	no market
Totals	**3,989**	**8,794**	**42**

With the base growth case, sales of tire-derived steel remain at less than 15 million pounds per year during the next five years, whereas a ½ percent penetration rate of the California iron and steel scrap requirements would yield an available market of more than 40 million pounds annually. Thus, from an overall market perspective, the base case, although representing significant penetration from the present situation, is well within the available target market for tire-derived steel.

It is difficult to rationalize that tire-derived steel could achieve an overall market penetration of even ½ percent without reductions in rubber contamination from current levels, coupled with better densification and packaging. The base case assumes that, as recycled rubber production increases, steel and fiber sales will dramatically rise from their current low penetration levels in the marketplace. Although data from the Task 2 survey about this issue are limited, specific examples of actual use indicate that tire-derived steel was being used at about 1 percent of the furnace charge rate. If this dilution rate is applied more broadly, it suggests that the market penetration in the defined categories is reasonable and the market can absorb tire-derived steel to this modest level. This reported dilution and penetration rate is well above the base case assumption of penetration at below $^{2}/_{10}$ percent of the overall steel scrap market.

The export market, the California market, or any of the Pacific Northwest states each appears to be positioned to absorb individually the increase in tire-derived steel assumed in the base growth case. Thus, the future tire-derived steel situation is not based on an assumption that TAMCO, the state's largest potential user of scrap-derived steel, is needed. Nor is it based on steel scrap customers in the Pacific Northwest taking tire-derived steel scrap sufficiently to achieve the projected growth. Thus, marketing flexibility is deemed to exist, provided that marketable grades of steel are recovered.

This study has not conducted a supply-demand balance for world steel scrap markets. However, available data suggest that export shipment growth is possible on a large scale for tire-derived steel with the right characteristics. Grupo Simec's steel operations in Mexicali, Baja, make major steel scrap purchases in the United States to satisfy a requirement of 30,000 to 40,000 metric tons purchased per month, but its purchases must be rubber-free. During Task 3 (supply and demand analysis), a Canadian tire processor reported that China is seeking 100,000 metric tons monthly of scrap steel, which does not need to be rubber free. Additional exports are also possible throughout the greater Pacific Rim countries as well. Again, quality and bulk density can be limiting. Scrap dealers may be unwilling to incorporate blends of tire wire into a scrap shipments for fear of having the load rejected, a costly proposition if it takes place in a foreign port. Thus, improvements in purity and densification of tire-derived steel will be needed in all likelihood. If the improvements are not forthcoming, the future outlook is more doubtful and long-transit movements would be less attractive in an environment of rising freight cost.

The base case assumes a significant percent annual growth in tire-derived steel (16 percent per year). However, on a weight basis, the increase in penetration amounts to capturing only an additional $^{1}/_{10}$ percent of the California domestic and export steel scrap markets. Insofar as increasing tire-derived steel sales are concerned, the local market can absorb additional tire-derived steel, if the steel meets required market standards. Moreover, the Pacific Northwest’s market for scrap steel is as large as California’s, and it may be able to take additional supplies as well. The Mexican mill of Grupo Simec may also be able to absorb some clean tire-derived steel. However, the real short-term opportunity for California processors lies in the export market. Hopefully, while gaining time with the international sales, processors can improve the quality of tire-derived steel and expand domestic sales as well during the next five years.

Fiber

The only known present market for tire-derived fiber in California is fiber TDF. With local demand for TDF falling back to the levels of the early 1990s, it is not clear that the market can absorb more fuel in the form of fiber TDF. During the study, the project team focused on non-fuel fiber outlets. Consequently, the project team is not certain of the future of California’s TDF situation. Nationally, fiber TDF (with its inherent low sulfur content) seems to have the potential for sustained growth, especially if conventional hydrocarbon fuels surge in price. Energy markets prices over the long term are difficult to forecast, but it seems certain that the average cost of energy will be higher than that of 2002, if unrest continues in the Middle East and elsewhere, and if the United States returns to a high level of economic activity and energy use during the next five years.

Each non-fuel use of fiber has some prospects for growth. Most of the non-fuel markets are potential outlets that need time to develop. Over the next five years, some modest growth can be expected if the quality of tire-derived fiber improves. Higher-purity fiber is needed for most new markets such as carpet underlay, soil amendment/erosion control, reinforcing additives, and mixed fibers (see discussion in section entitled “Identification of Products or Potential Product Applications”). Paradoxically, whereas the market requires higher purity and will not buy fiber until that purity is assured, processors cannot justify the investment to achieve higher purity until they have secure markets.

Providing samples of recovered tire-derived fiber to waste fiber dealers and consumers should be a priority. The molding of fibers into composites (for example, the ReSyk system offers an outlet where “as is” tire-derived fiber may apparently be acceptable now). If a “large” operation using the ReSyk equipment is about 500,000 pounds annually, a relatively sizable number of these operations would be needed to have a significant impact on the available fiber supply for California. Asphalt systems have the advantage of both the large potential fiber use as well as less stringent purity requirements. Unfortunately, no specific asphalt outlets have been determined for tire-derived fiber. Nevertheless, continued attention to new developments is warranted.

The outlook for tire-derived fiber entails major uncertainties, since the market development is in such an early state. Although industrial fuel users should be able to take all of the domestic low-sulfur, high-BTU fiber available from tire processors, the contraction of California's TDF market since 1995 raises doubt.

Several tire-derived fiber developments are potentially promising, particularly if fiber can be made clean enough. However, the situation is not quite so simple. Should the quality hurdle be resolved, the marketplace will evaluate other product characteristics more carefully. Most applications have a set of cost performance curves with some minimum required physical properties for competing materials. Even if tire processors could somehow separate a product that approaches the equivalence of a pure polyester tire cord, the fiber would still not be acceptable for some applications.[11] The fiber thickness, elongation, melt temperature, crimp, and moisture content are just a few examples of other properties that might rule tire-derived fiber out of specific applications.

Many proposed applications for tire-derived fiber are sensitive to fiber length, which presents a barrier if processors cannot alter the fiber length to meet the market needs. In the survey results, no fiber was reported as longer than 1 inch, with an average length of ½ inch. The actual length of tire-derived fiber results from seeking a high crumb rubber yield through successive grinding of material. A number of the potential fiber applications need a longer fiber length. Preferred fiber lengths are ¾ inch for concrete additives, 1¼ to 5 inches for erosion control, and 2 to 3 inches for carpet underlay, as well as longer required lengths in other niche applications. If processors can alter their fiber length and reach necessary quality standards, the selected California non-fuel fiber markets needs are over 30 million pounds annually.

The demand for tire-derived fiber is uncertain because development breakthroughs are required before consumption growth can take place in the new markets. Thus, California processors are faced with the possibility of having to continue to dispose of tire-derived fiber, at least in the near term, unless local energy consumers are available.

[11] It is interesting to speculate on the hypothetical case of processors actually being able to line up tires with the same construction, allowing the recovery of fiber with uniform properties and a purity similar to home scrap. This prospect is unlikely. If it could be done, additional markets would be immediately available domestically. Further, the export markets would be able to absorb most of the tire-derived fiber. The export markets seek waste fibers that can be reused in a cheaper, lower-quality version of the applications for the virgin fiber. However, at the right price, the market is normally robust. Of course, if the tire-derived fiber is a uniform fiber type with little contamination, it might also be recycled back to resin. Collection and freight charges to the recycling operation would probably limit this outlet. Prices of tire-derived fiber of a quality similar to home scrap would still be well below those of home waste polyester because of fiber length. On the other hand, a portion of the reported price in the Task 2 survey of $0.75 per pound for polyester home scrap is well above the giveaway level typical of 2002 values for tire-derived fibers.

Comparisons

The U.S. market offers selected opportunities with greater potential than those in the California market. The scrap steel market is much larger in the U.S. steel belt, which stretches from Wisconsin to Pennsylvania, than in California. Prices for scrap steel are much higher as well.

The use of TDF declined in 2001 across North America, according to the Rubber Manufacturers Association. However, despite the dip, the growth for the period from 1999 to 2001 averaged over 9 percent per year. Fiber TDF has found acceptance in many parts of the country, and use is being sustained at a rate of growth that is expected to be more than twice that of the gross domestic product through 2007. The California situation is markedly different for rubber and fiber TDF. Rubber TDF has declined in California over the last seven years.

Other comparisons are presented in Chapter 2 and are not repeated here. One point to emphasize is that processors with clean steel and fiber by-product tend to be more successful at marketing high-quality products. Conversely, the survey results indicate that California respondents tend to produce, on average, less pure steel and fiber, than processors in other states or countries do, suggesting that commercial markets are more closed to them than to producers with cleaner products. Thus, opportunities are restricted if lower quality steel and fiber are offered.

Canada is the major producer of rubber modified with fibers, whereas there are apparently few producers of these products in the United States. Generally, all market segments will remain modest opportunities until the level of rubber contamination in tire-derived fiber can be reduced. In addition, most non-fuel applications for tire-derived fiber with which humans or animals come in contact require complete steel removal for the fiber to be seriously considered. Other possible applications could not be effectively evaluated because no tire-derived fiber sales were identified or because substitute product applications could not be found.

Approximate quantities of tire-derived steel and of fiber reported sold in the United States are shown in Table 54. Because the number of processors selling tire-derived steel and fiber is quite small overall and because participation in individual markets is smaller still, these ranges are provided to maintain the confidentiality of the information provided as a result of the survey. With regard to demand for fiber, only reinforced additive for rubber, plastics, and composite materials are projected to reach the large market stage by 2007.

Based on the results presented in Table 54, most applications remain relatively small outlets for tire-derived by-products. Directly following Table 54 are discussions of results indicated in the table that summarize the opportunities and limitation issues covered in the Demand section: Identification of Products or Potential Product Applications. The plus signs in Table 54 stand for the potential increase in market size, given quality improvements that allow the market to expand. Applications may have multiple quality issues or only a single consideration that effectively blocks the market. Improving only one quality attribute (for example, decreasing rubber contamination) may not be sufficient to create a market opportunity.

The limits on growth for tire-derived steel and fiber are discussed in the next two subsections. Rapid penetration of some markets is projected simply as a result of eventually reducing the level of rubber contamination in the product streams to appropriate levels. Significant growth of tire-derived by-products in other potential end uses may require complete removal of rubber.

Table 54. Range of Sales of Tire-Derived Steel and Fiber in North America (1997 to 2007)

	1997	2002	2007	Low Rubber Content[a]	No Rubber Content[a]
Steel					
• Steel scrap	small	growing	growing	++	+++
• Fiber-reinforced concrete	no present market	no present market	trace		
• Low-value wire applications	no present market	no present market	no expected market		
Fiber					
• TDF	small	growing	growing		
• Reinforcing additive for rubber, plastic, and composite materials	small	growing	large	++	
• Concrete additive	trace	small	small		++
• Soil amendment, mulch, and erosion control	no present market	trace	trace	+	
• Packaging or blanketing materials	no present market	trace	trace	+	++
• Sound deadening, filtering media, and insulation	no present market	no present market	no expected market	++	
• Stuffing and filler	trace	small	small	+	++
• Carpet underlay	no present market	no present market	small		++
• Asphalt additive	no present market	no present market	no expected market		

Trace = Under 1 million pounds.
Small from 1 million to 5 million pounds]
Growing = over 5 million to under 100 million pounds.
Large = over 100 million to 500 million pounds.
[a] Number of "+" symbols denotes potential increase in sales (+++ = largest increase).

Steel Results From Table 54

Steel Scrap: This complex market presents selective opportunities for tire-derived steel. The three most significant barriers are the level of attached rubber, the low density of tire wire after the tire recycling process, and matching tire-derived steel to the metallurgy requirements of customers. The bronze or brass coatings of tire wire, plus other metallurgical issues, can be limiting. Steel content above 90 percent becomes increasingly salable with higher concentrations, and steel content above 99 percent would normally be acceptable commercial material. Steel sold directly to mills/foundries normally has to be densified by compaction or bundling.

Although a market exists for tire-derived steel, not all processors will be able to serve it, and it may be intermittent as market conditions fluctuate.

Steel Fiber-Reinforced Concrete: Rubber-free and rust-free steel are needed to approach this market.

Low-Value Wire Applications: No wire applications were found. A more detailed investigation, which is beyond the scope of the current study, might identify applications for evaluation.

Fiber Results From Table 54

Tire-derived fuel (TDF): Quality is not an issue for most fuel applications. Poor-quality fiber is desirable with TDF, as cement kilns can make use of the rubber as a heat source and steel is consumed as a needed raw material of finished cement. Water content of the fiber and the customer's ability to handle fiber in its feed system are potential limitations.

Reinforcing Additive for Rubber, Plastic, and Composite Materials: Few real opportunities were discovered for using mixed, loose, tire-derived fiber as an additive. A few large, company-specific uses were noted, however.

Concrete Additive: Synthetic fibers, as well as steel fiber, are used to increase concrete integrity. Fibers that are dirty or have attached rubber will not be considered commercially, however. This application is also sensitive to fiber length.

Soil Amendment, Mulch, and Erosion Control: Although no overall market was found, isolated applications do use mixed and polyester fibers, and this situation might translate into opportunities for tire-derived fiber. The length of the fiber may be limiting, and the inclusion of rubber and metal probably excludes some applications because these contaminants tend to clog delivery equipment, such as spray nozzles.

Packaging or Blanketing Materials: Steel in the fiber poses a liability issue and is not acceptable. Rubber inclusions in processes with heating can melt, affecting appearance or characteristics of the final product or disrupting the flow, especially in spray processes. Needle-punch joining techniques may not be able to tolerate rubber.

Sound Deadening, Filtering Media, and Insulation: Some applications can tolerate rubber, but steel inclusion poses a liability issue.

Stuffing and Filler: Steel inclusions pose a liability issue. Rubber inclusions in processes with heating can melt, affecting appearance or characteristics of the final product.

Carpet Underlay: Steel in the fiber would pose a liability issue and would not be acceptable. Rubber inclusions, in processes with heating, can melt, affecting appearance or characteristics of the final product. Needle-punch joining techniques may not be able to tolerate rubber.

Asphalt Additive: Rubber and steel inclusions should not be a problem. However, projects may specify the use of a particular fiber, not a mixed fiber. Fiber length may be an issue. Although fibers are used in some situations, no clear opportunity was identified for tire-derived fiber.

International Area Comparisons

The Task 2 survey did not reveal application differences among steel and fiber by-products in the United States, Canada, and Europe, although as mentioned previously, the survey results did contain information on the operations of NRI Industries in Canada. The market for rubber-based TDF in North America is almost twice as large as the market in Europe, presumably making it easier for North American processors to introduce fiber TDF.

Table 55 shows the wide global dispersal of steel production (and, therefore, scrap requirements). North America produces only 15 percent of the total steel produced in the world. Europe, China, Russia, other countries in the Commonwealth of Independent States (CIS), and other Asian countries are all areas with substantial production and scrap requirements.

Table 55. 2002 Steel Production by Region of the World

Area	Percent of World's Steel Produced
Europe	24.1
PR China	17.4
North America	14.6
Russia, CIS	11.8
Rest of Asia	11.8
Japan	11.6
South America	4.5
Africa	1.8
Middle East	1.4
Oceania	1.0
Total	**100.0**

Processors' characteristics, such as small size and limited resources, are similar in the United States and internationally.

Europe and Canada are ahead of the United States in fostering new markets for recycled products. The European market for all non-fuel tire-derived products is 25 percent larger than that for North America. Many Canadian provinces and European countries have incentive systems or regulations (for example, payments for rubber, steel, and fiber sold and landfill prohibitions) that reduce or eliminate the land disposal of tires or processed rubber, steel, or fiber in landfills and drive commercial uses of tire-derived materials. These incentives are still insufficient for processors in central Canada and other locations that are not within economic shipping distance of consumers of tire-derived steel or fiber. The commercial markets, plus governmental programs or regulations, can have marked impacts near international or state borders. A governmental mandate to process tires could instead cause the waste tires to be exported across a border, where regulations are less demanding. California is a net importer of waste tires because a demand for recycled rubber has been developed and simple economics of delivered costs for the waste tires dictate. The survey found reports of southern Oregon tires being processed in northern California, and Mexican tires from the border region being processed in southern California. Presumably, waste tires cross the Nevada border as well.

Market Segmentation

Tire-derived steel has only one commercial market, scrap steel. Tire-derived fiber is more easily segmented by its market applications.

Steel

Using price, the scrap steel market can be segmented by the type and quality of the scrap, as well as location of the market. Market segments for tire-derived steel are affected by the same underlying conditions as those of the scrap steel market, in addition to tire-derived steel's own set of characteristics.

Price: As indicated in Chapter 2, the price information collected is not uniform. Factors that account for the variations are local market considerations, regional differences, the role of scrap dealers, and type of steel.

ISRI's grading system breaks ferrous scrap down into approximately 120 classifications. It is not clear that the market distinguishes among all of these grades, given the many fewer grades reported (22) by the U.S. Geological Survey's statistical collection system, and the prices from various sources, which are reported covering less than a dozen categories. Differences among ISRI classifications are likely to be the basis in price negotiations or arbitration clauses establishing a contract or spot price through the mechanism of a standard base price plus or minus an agreed- upon differential.

On February 19, 2003, the *Recycling Manager* newsletter reported the U.S, average steel scrap prices shown in Table 56, with shredded auto body prices significantly higher than other steel scrap products. As shown in the table, prices differ markedly among scrap types. In the marketplace, the price of tire-derived steel is sometimes compared with the prices for No. 2 bundles and steel cans. The price estimates in Table 56 are the selling price to consumers. Prices to steel scrap dealers will be significantly lower.

Table 56. Steel Scrap Prices in the United States (2002 to 2003)

Scrap Material	February 2003 (dollars/ton)	February 2002 (dollars/ton)
No. 2 bundles	61	56
Shredded auto scrap	103	89
Used steel cans	66	56

Source: *Recycling Manager*, 2003.

Prices also clearly differ by region. The price differences for heavy melting no. 2 indicate that the West Coast market price for this type of scrap in the 1995-to-2000 period varied from approximately $30 to $100 per long ton (long or gross ton equals 2,240 pounds). The January 30, 2003, price differentials for heavy melting no. 2 grade scrap steel purchases for export, between California and the East Coast, were $52 to $60 per long ton. The steel mills that are concentrated in the "Steel Belt" region of the United States tend to set the domestic price, with other area prices being established to reach the main market. Accordingly, West Coast prices are based on local conditions, the export price, and Steel Belt price less transportation. The differences in 2002 unit trade values (price) of exports across the country are much narrower ($96 to $110 per metric ton [2,204.6 pounds]), with low and high price varying across the country. Imports tend to keep the regional differentials. (Hess, et al., 2001.)

In 2002, the West Coast import unit trade value was $15 per metric ton lower than the national average.

Scrap dealers and blend service companies provide assistance by aggregating supplies, blending scrap from different sources, adjusting inventory of stocks to meet demand, and finding customers. Because these services require resources, the scrap dealer's price includes a markup, which a Rand study suggests can range as high as half of the selling price (Hess, et al., 2001). Accordingly, if processors entered into direct negotiations with scrap consumers, they might increase their revenues. However, some activities and associated costs borne by the scrap dealers would then shift to either the consumers or the processors, possibly resulting in a negligible increase in net return to processors.

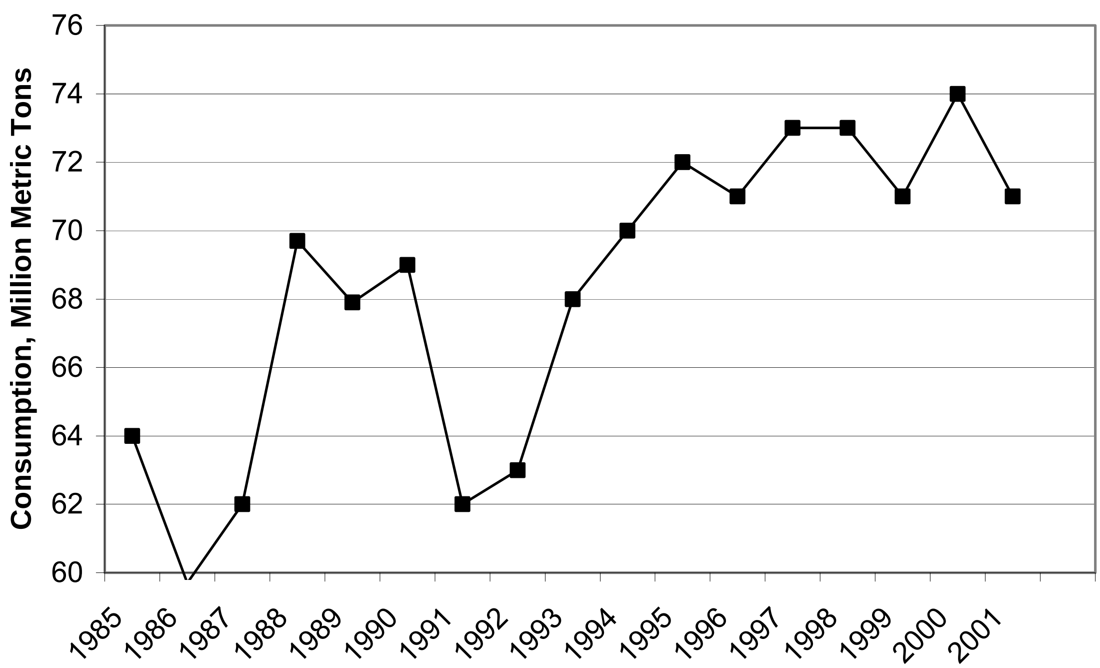
Dealers and companies providing tire-derived steel scrap that meets customers' specifications may conduct additional processing steps such as baling, compacting the tire wire, or burning off the rubber. Because these processing steps are difficult for tire processors to justify without ongoing dependable outlets, they may rely on large scrap dealers and service companies to further process and blend scrap supplies and to serve as the means for processors to sell into the scrap metal market.

The study team found that a smooth, mathematical relation could not be established between selling price of scrap and amount of rubber contamination. However, it is clear that tire-derived steel containing low percentages of rubber contamination is generally saleable and commands a higher price than substantially contaminated scrap. The lack of a homogeneous commodity market for tire-derived steel means that precise differentials for quality, packaging (loose, baled, or compacted), and volume cannot be precisely determined.

The available market for tire-derived steel changes with movements in the supply and demand cycle for scrap steel. For example, during the 25-year period from 1974 to 1998, average scrap steel prices showed minimums in 1977, 1982, 1985 to 1986, 1991 to 1992, and 1998 ("Iron and Steel Scrap Statistics," December 2, 2002). These years would also likely have been periods when tire-derived steel would have had lower prices or been market-restricted.

Iron and steel scrap consumption in the United States was down in 1986 to 1987, 1991 to 1992, 1996, 1999, and 2001, as shown in Figure R. This pattern reinforces the sense that steel scrap markets have demand cycles that affect and will continue to affect marketing of tire-derived steel.

Figure R. U.S. Iron and Steel Scrap Consumption



Source: Based on data from U.S. Geological Survey, 2002.

Fiber

Tire-derived fiber segments are effectively categorized by application markets, although the segments are not large. See Table 54 for segmentation by fiber application areas.

Tire-derived fiber is not separated commercially into uniform mixtures that can be segmented by resin families such as polyester, nylon, or a fiber-resin grade. All tire-derived fiber is a non-uniform mixture of tire fabric and cord grades and resin families, dominated by polyester but including nylon and possibly other fibers. No industry standards exist for tire-derived fiber.

Industrial Communications

Communications between processor and scrap steel dealers, mills, and foundries, are few. The Task 2 survey revealed that most scrap steel dealers have no contacts with processors, and that few steel mills or foundries are in direct contact with processors. Some mills and foundries use third parties to prepare scrap deliveries to their specifications, thus further reducing contacts between processors and end users. Moreover, most processors are too small to justify commercial development in export markets or areas beyond their local markets.

Fiber processors' communications fare worse than those for scrap steel processors. No contacted waste fiber dealers indicated communication with waste tire processors. Processor secrecy about commercial customers and applications is common because local opportunities are isolated and have not coalesced into regional or niche markets. Word of mouth is the medium of communication. No business-to-business and supply-chain management systems were cited.

Chapter 4. Market Barriers—Methodology and Analysis

As a consequence of the analysis, CalRecovery identified a number of barriers to recycling and use of tire-derived steel and fiber. Some of the identified barriers and issues are considered relevant generally; that is, they are independent of geographical location. Others are particular to California for a variety of reasons. Barriers have been identified for both tire-derived steel and fiber. However, the recycling of tire-derived fiber is subject to a much poorer market situation than is the case for tire-derived steel.

Potential Types of Barriers

The evaluation considered that the recovery and use of tire-derived steel and fiber might be subject to the types of issues listed below:

- Product quality.
- Technological.
- Environmental.
- Fiscal.
- Competition.
- Regulations and permitting.
- Consumer acceptance.
- Legal.
- Tariffs, subsidies, and incentive programs.
- Logistical.
- Potential benefit of vertical integration.

Analysis and Results

Existing Conditions

The results of the literature search and industry survey clearly established the fact that recovery of steel and fiber from waste tires is solely an adjunct to the processing of waste tires for recovery of products predominantly of rubber. These products include crumb rubber and tire chips for use as fuel, plus civil engineering and landfill applications. Bead wire is also recovered by some companies that are making rubber products directly from tires by sectioning or stamping. Essentially, market demand is not sufficient to promote large-scale recovery of tire-derived steel and fiber. Thus, the recovery of steel and fiber is primarily—if not exclusively—motivated by minimizing residue disposal costs, rather than producing a marketable product with a well-defined set of uniform characteristics and other necessary properties. This factor is the cause of many problems for producers of steel and fiber by-products, and it has created barriers to successful diversion of these materials.

Steel

The results of the analysis indicate that clean steel can be recovered from waste tires and marketed. The cleaner the steel, the more probable and reliable the marketing opportunities. The largest and best market for tire-derived steel in the United States is scrap steel for production of steel and iron. California has only one steel mill in the state; however, a preliminary analysis reveals other potential users of California-produced tire-derived steel are likely located within economic reach of processors. The key variables affecting the marketability of tire-derived steel are purity in terms of rubber contamination and packaging of the recovered material, namely appropriate bulk density and physical form. CalRecovery believes that demand for scrap steel is adequate to absorb tire-derived steel if it were produced to user specification. Thus, demand is not constrained by supply. On the other hand, the quality and physical form must be sufficient to meet the scrap steel requirements. Based on other investigations and results of this project, the technology exists to meet the market specifications. Because of this relatively simple situation in terms of market requirements, the issues and barriers affecting recycling of tire-derived steel are relatively few, especially compared to those of tire-derived fiber.

Fiber

The recovery of tire-derived fiber for recycling and sale is uncommon, both in the United States and in international locations. The few instances of recovery and use of tire-derived fiber that the study identified can be classified as special and localized. Only one example of recovery and use of tire-derived fiber in California (as a fuel commodity) was reported to us in the processor survey. Due to the lack of production of marketable fiber and experience in its use, a number of issues and barriers exist to production of marketable tire-derived fiber.

Issues and Barriers

Steel

The key issues and barriers for steel, described in Table 57, are associated with product quality/ material characteristics and customer acceptance. Technological remedies greatly reduce the significance of these barriers. The other issues and barriers rank substantially below the previous two in terms of significance.

Table 57. Summary of Issues and Barriers Related to Recycling of Tire-Derived Steel

Issue Category	Barrier
Product quality/ material characteristics	Marketable grades could be produced with existing technology. However, lack of characterization data and of production samples are substantial deterrents to marketing tire-derived steel. These problems are of substantial magnitude in California. In this state, the historical record of tire-derived steel production is based almost exclusively on disposal avoidance, as opposed to being driven by market demand and the requirement to meet the specifications of particular uses. The characteristics of tire-derived steel vary for bead, belt, and body wire, and the wire grades contain constituents (for example, those of the alloy coatings) that are deterrents to use in some metallurgical applications. Some potential new product applications may need a specific length or physical form (for example, steel fiber-reinforced concrete may need a specific length of steel wire).
Technology	Technology exists to produce steel with low rubber contamination, although system suppliers are limited in number. Some users require densified forms of wire feedstock. Compacted steel can be produced by some types of densification equipment, although the densification history is unproven on a large scale. Processors may lack capital to invest in the required type(s) of equipment, particularly if markets are uncommitted or a long period of market development will be needed. Data on the consequences of improving steel fraction purity is lacking. For example, improving purity of steel may lower yield of fiber and may affect crumb rubber production efficiency.
Environmental/safety	Depending on the form of processing, tire-derived steel can have small, sharply pointed particles that represent potential risks to those handling the material. The risks are considered primarily occupational and are not a general public hazard. Rubber contamination in tire-derived steel represents a potential problem in the form of the need for control of sulfur emissions if the steel fraction is subjected to thermal processing, such as in the manufacture of steel. Rubber contamination in recovered steel can result in operating problems related to environmental protection and to worker safety, for example, smoke formation, auto-ignition, and premature combustion of rubber-contaminated steel on feed belts.
Fiscal	Tire-derived steel typically produced during manufacture of crumb rubber requires additional equipment and capital outlay to achieve the quality desired by high-end markets or to sustain marketability in times of slack scrap steel demand. Inadequately cleaned and packaged steel affects the economics of steel manufacture. Examples are extra handling in the yard, vaporization in the furnaces, and blending and inventorying. Therefore, tire-derived steel can be less appealing than other types of scrap to steel mills and iron foundries.

Issue Category	Barrier
Competition/ adversaries	Given the estimated size of the scrap steel market, the comparatively small supply of tire-derived steel is not seen as sufficient to warrant substantial interest from competing sources of supply. Currently, tire producers and their suppliers appear to be indifferent on the issue of recycling of tire-derived steel. They would probably not change their opinion unless tire performance, unit cost, or customer satisfaction were adversely affected.
Regulations and permitting	In the case of tire processing, no substantial regulatory or permitting barriers have been identified. However, the study has identified some potential end user (for example, steel mill) safety problems associated with premature ignition, falling loose wire, and handling tire wire during feeding operations.
Customer acceptance	There are 3 issues that have been identified in this category: (1) the need for low or no rubber contamination, (2) appropriate densification and physical form, and (3) alloy content. The last issue apparently is not an overriding one due to availability of other sources of steel and the "typical" mixing ratios employed by steel middlemen and steel/iron mills. However, mixing adds another layer of cost to the user, thus reducing the number of dealers and mills willing to consider tire-derived steel. The first and second issues can be circumvented by imposing commercially available technology.
Legal	No significant legal issue was identified.
Tariffs and subsidies	Subsidies offered by out-of-state entities can increase the economic range of crumb rubber markets for out-of-state processors such that they could enter California, thereby displacing California crumb rubber and resulting in less potential recovery of California produced tire-derived steel. Thus, the supply and recycling of tire-derived steel in California can be adversely affected under these conditions.
Logistical	High-quality, densely-packaged tire-derived steel likely can support markets hundreds of miles from the processing facility.
Potential benefit of vertical integration	Due to anticipated demand for high-quality tire-derived steel and the technical ability to produce it, no substantial incentives exist for vertical integration. Integration of steel-making operations with tire processing facilities would require that tire processors become proficient in steel-making and compete against a well-established industry and producers. The annual quantities of tire-derived steel produced by a typical tire processor are insufficient to stock a dedicated steel mini-mill. Thus, the processor would need to acquire additional steel scrap supplies. Processors selling directly to users could potentially improve overall profit. However, other marketing, inventory, and freight costs may offset the advantage of the direct marketing approach.

Fiber

Issues and barriers for tire-derived fiber are summarized in Table 58. The key issues and barriers for fiber are lack of data on product characteristics and material properties, lack of markets and customer acceptance, and potential legal issues. Technical solutions may not be sufficient to remedy the barriers. The lack of markets and marketing experience for tire-derived fiber increases the consequences of the barriers.

Table 58. Summary of Issues and Barriers Related to Recycling of Tire-Derived Fiber

Issue Category	Description
Product quality/ material characteristics	Data are lacking on required product quality as a function of types of uses. Little data are available concerning types of uses. Data are also lacking on characteristics of various types of tire-derived fiber that could be produced, especially to meet market requirements in California. The inherent mixed resin composition and fine particle size of current tire-derived fiber production translates to low end uses and, therefore, to limited market demand. Material drawbacks identified by the study include the following: lack of product consistency, fiber length may be too short for applications, fiber is contaminated (for example, with rubber), and fibers are hydroscopic.
Technology	Commercial availability of equipment to recover clean fiber is limited and may be unproven. Therefore, technology may not exist to recover fiber of sufficient quality to meet market requirements. Data are lacking on the consequences of improving fiber fraction purity. For example, increasing purity may lower yield of fiber and may affect crumb rubber production efficiency, etc.
Environmental/safety	Depending on the form of processing, fibers may be very finely sized particles. This could cause nuisance dust and a need for particulate control. The potential of steel entrained with the recovered fiber may pose safety problems to workers and to the public (when handling/using a product).
Fiscal	Tire-derived fiber produced during manufacture of crumb rubber requires additional equipment and capital outlay to achieve the status of a marketable commodity, other than for very low-end uses.
Competition/ adversaries	Suppliers of virgin resin and home scrap could consider tire-derived fiber to be a much lower-priced competitor where tire-derived fiber would be an adequate replacement. Tire-derived fiber, even if processed sufficiently, would likely compete for an already limited set of markets, especially in California. Substantial new product development would be required before tire-derived fiber would be a threat to producers of single resin fibers.
Regulations and permitting	No significant regulatory or permitting barriers were identified for tire processing facilities. For end users that might combust tire-derived fiber, rubber contamination could result in emission control problems. This could increase costs of production.

Issue Category	Description
Customer acceptance	Tire-derived fiber containing any sharp steel particles is an unacceptable risk to the public and therefore to manufacturers of any consumer products that would contain tire-derived fiber. New applications for tire-derived fiber likely will be limited and slow to gain acceptance. This is due to the need to demonstrate cost effectiveness, to achieve customer qualification, and to produce acceptable job or end use specifications. Currently, tire producers and their suppliers appear to be indifferent on the issue of recycling of tire-derived fiber. They would probably not change their opinion unless tire performance, unit cost, or customer satisfaction were adversely affected.
Legal	Litigation could result from injuries sustained from use of products containing steel-contaminated tire-derived fiber.
Tariffs, subsidies, and incentive programs	Subsidies offered by out-of-state entities can increase the economic range of crumb rubber markets for out-of-state processors. These processors may displace California crumb rubber and cause potentially lower recovery of California-produced tire-derived fiber. Thus, the supply and recycling of tire-derived fiber in California could be adversely influenced. Diversion incentives offered by the State for tire-derived fuel (TDF) projects appear to encompass only rubber-based TDF and do not appear to address or encompass tire-derived fiber.
Logistical	If there are markets, a combination of low product value and the effort required to produce fiber of adequate quality means profitability is very sensitive to packaged density and distance to markets.
Potential benefit of vertical integration	Vertical integration could conceivably reduce the barriers associated with use of, and market demand for, tire-derived fiber. The study found one example of a supplier of a molding system (unproven) that could use fibers to manufacture commodities (the fiber serves reportedly as a filler). To manufacture high-end commodities, tire processors would probably have to become knowledgeable and experienced in certain commodity markets and uses. This would require knowledge of manufacturing methods not normally associated with tire processing.

Chapter 5. Cost-Benefit Analysis—Methodology and Results

In this chapter, a cost-benefit analysis is presented for recovery of steel and fiber from the processing of waste tires in California. Primary objectives of the analysis are to determine the potential profitability of recycling tire-derived by-products and the key factors affecting the economics and profitability.

The analysis is based on the incremental costs of recovering marketable grades of steel and fiber and estimates of revenues associated with recycling these materials. The primary bases of the analysis are the results of the industry survey and of the supply and demand analysis.

Methodology and Analytical Parameters

As the starting point of the cost-benefit analysis, CalRecovery analyzed generalized process flow diagrams for steel and fiber recovery based on information gathered previously in the study and on supplemental information collected. The cost-benefit analysis is based on incremental processing to achieve marketable recovered steel and fiber. The processing equipment assumed for the analysis is that necessary to produce marketable grades of steel and fiber from the manufacture of crumb rubber. Crumb rubber production produces the highest yield of steel and fiber from among the various major types of tire processing alternatives (for example, tire chip production).

After defining generic processing configurations, CalRecovery estimated capital and operating costs as well as revenues from sale of the recovered products. Analyses performed in connection with the stakeholder survey and the supply and demand analysis revealed, at least on a preliminary basis, that key parameters governing the recycling economics of recovered fiber and steel were level of recovered product quality and distance to markets.

Sale prices for the recovered commodities are difficult to estimate due to a lack of sufficient marketing history in California. Therefore, CalRecovery estimated sales prices based on those reported across the United States in the Task 2 processor and market surveys, and on CalRecovery estimates of the selling price of the recovered products, depending on quality. In the case of tire-derived steel, the key variable determining selling price was percentage of rubber contamination of the steel fraction. CalRecovery assumed a functional relationship between selling price and degree of rubber contamination. It was also assumed that the steel would be properly densified to meet the delivery, packaging, and feeding requirements of the user. Thus, the processing configuration is assumed to contain densification equipment (for example, a baler). The user of the recovered steel was assumed to be a steel mill or iron foundry.

To perform the economic analysis, certain financial parameters were used; including interest rates for capital equipment loans and estimated economic life of equipment. The financial parameters, as well as others, are described later in the analysis.

In addition to performing the cost-benefit analysis described above, CalRecovery also explored the costs to transport recovered by-products, to landfill by-products, and to develop specific recycling industries for these tire-derived materials.

Processing Systems and Quantities

The steel and fiber processing subsystems, respectively, would be installed at the processing facility to recover greater yields of steel and of fiber. The subsystems would accept the steel and fiber fractions that are typically produced at crumb rubber facilities in California. For the economic analysis, an average of 3 pounds of steel fraction and 2 pounds of fiber fraction per PTE were assumed available for recovery.

The crumb processors in California that completed the processor survey reported a variety of tire processing rates, generally within the approximate range of 3 to 5 tons per hour (TPH), or about 2,400 to 4,000 PTEs, eight hours per day. For the economic analysis, an average facility processing rate of 10 TPH of PTEs, or 80 tons per day (TPD), assuming an 8-hour day was selected. The selected processing rate was a compromise among the typical crumb processing rates in California, those in other states, and the fact that certain cleaning equipment (for clean steel recovery) is commercially sized for facilities processing at least 10 TPH of tires.

In the process of removing rubber from the steel and the fiber fractions (rubber is present in adhered as well as loose, particulate form), rubber is freed for recovery as a by-product of the recovery operations. It was assumed, based on informal discussions with those familiar with waste tire processing and cleaning system equipment, that most of the rubber is, or can be, easily recovered from rubber-contaminated steel or fiber by cleaning systems on the market. However, publicly available commercial history is lacking for both types of cleaning systems (that is, for steel and for fiber). Because of the systems that have been designed and are available in the marketplace, CalRecovery has assumed that the steel stream and the fiber stream would be processed in separate subsystems. However, some integration between subsystems likely may, or could be, achieved if both steel and fiber streams were intended for beneficiation.

Steel

In the case of beneficiation of steel, a 99.0 percent yield of steel in the product stream was assumed—that is, 1 percent of the steel is lost during processing due to inefficient separation or other forms of process losses. Therefore, the steel processing system would recover an estimated 11.88 tons per day of steel as product for sale.

The key unit operations of the steel recovery system are assumed to be magnetic separation and baling. The loose bulk density of processed tire steel is probably sufficient to achieve 75 to 100 percent of maximum allowable tractor/trailer payloads. Baling of steel wire is assumed in the analysis in order to provide users with feedstock that is convenient and safe to handle and process. This was a key requirement found during the market demand analysis. Rubber-belt conveyors are used for transporting process streams among the key unit operations.

Fiber

A recovery rate of 95.0 percent for the fiber product was assumed; which means that 5 percent of the fiber is lost during processing. Approximately 7.6 TPD of fiber would be recovered as product for sale.

The key unit operations of the fiber recovery system are screening and baling. Baling is assumed in order to provide users with feedstock that is convenient and safe to handle and process, and to minimize transportation costs for fiber, which, uncompacted, is low-density material. The performance and operation of most fiber beneficiating systems requires that the feedstock be essentially free of steel contamination. Rubber-belt conveyors would carry the dense process residues (for example, rubber particles). Rubber-belt conveyance or pneumatic transport would be used to transport the low-density fibrous fractions.

Crumb Rubber

CalRecovery has assumed that the incrementally recovered rubber would be in finely sized crumb form and of a purity that would meet current market requirements. It was also assumed that all rubber removed to meet product quality standards for steel and fiber would be fully recovered for sale as crumb rubber, and that market demand would exist for this product.

Key Assumptions

In developing the conditions for the economic analysis, the following key assumptions were incorporated into the analysis:

1. One full-time equivalent staff position assigned to operate equipment, monitor operations, and handle materials.
2. Capital equipment amortized over a 20-year economic life and 6 percent annual interest rate.
3. Sufficient existing area and utility capacity in the facility to accommodate the addition of incremental beneficiation processes without requiring capital outlays.
4. Annual expenses of $10,000 associated with developing or sustaining markets of recovered product.
5. Quantities of residue from incremental processing of by-products is insignificant.
6. The “typical” waste tire processing system produces 15 percent rubber contamination in steel fractions and 40 percent rubber contamination in fiber fractions.
7. The rubber recovered by incremental processing is sufficiently clean to be saleable as crumb rubber.
8. Steel, fiber, and rubber products are transported to users by combination truck/trailer vehicles.

The high levels of cleanliness required for marketability for both tire-derived steel and fiber have not been proven by long commercial equipment operating histories. Therefore, CalRecovery’s analysis considered a range of product-purity levels (and, therefore, selling prices) for tire-derived fiber that might be expected for a given type and cost of processing system. Thus, some of the results (for example, the curves of Figures U and V, which appear later in the “Results” section) are reported parametric with product purity. CalRecovery has assumed the use of equipment that reportedly can achieve the highest-quality product that it believes is required by the steel and fiber markets, despite the fact that, in actuality, the product purity might be less than the claims made by manufacturers. In other words, capital and operating costs for the economic analysis are estimated conservatively, based on the best available information.

Market-Related Parameters

Selling Price

Steel

Based on results of the stakeholder surveys and the supply and demand analysis, the steel scrap market was selected as the base case for estimating the economics of recycling steel from waste tires. Using data available from the survey and the supply and demand analysis, CalRecovery developed a relationship between selling price and level of rubber contamination. Rubber contamination is one of the more important variables affecting the marketplace pricing of tire-derived steel. According to the results of the processor survey, the highest estimated selling price for tire-derived steel (about $55 per ton) can be realized only if the steel is devoid of rubber—that is, with 100 percent purity. This level of purity is probably not consistently achievable with existing equipment and processes, based on the information available to CalRecovery.

Fiber

Very little pricing data was identified related to the marketing of fiber. Utilizing available data, CalRecovery's estimate of the selling price of clean tire-derived fiber is that it would range between $0.0025 and $0.10 per pound (or $5 to $200 per ton) if the rubber contamination ranged between 12 and 1 percent, respectively. The types of use (markets) and the associated selling prices are two of the more uncertain elements affecting the cost-benefit analysis.

Crumb Rubber

The base case analyzed in the study assumed that the market price would be $350 per ton for any crumb rubber recovered as a result of beneficiating the steel or fiber fractions. This estimate is based on the average of the average yearly pricing data for 20-, 30-, 40-, and 80-mesh crumb rubber, as reported by *Scrap Tire and Rubber Users Directory 2002* (p. 71). While the analysis for the base case assumes a $350 per ton price for recovered rubber, markets and demand for fine-mesh crumb rubber may be limited in California.

Distance to Markets

Steel

Based on the results of previous tasks, markets for tire-derived steel produced in California are located on the Pacific West Coast, Baja California, and in the Far East. The Far East markets are serviced by several container ports located in California. Consequently, the distance to market could be tens of miles to perhaps 700 miles (for example, from Oakland to a steel mill in Mexicali, Baja, Mexico). Both road and rail transport are considered viable options to reach the points of sale, depending on transit distance, proximity of rail lines, and other factors. The base case analysis assumes that the user is 100 miles from the processing facility.

Fiber

The base case analysis assumes a distance to the fiber market of 100 miles, since the typical quality of the recovered fiber could likely support only markets in close proximity to the waste tire processing facility.

Transportation Costs

CalRecovery estimated costs of transporting densified by-products to markets based on truck/trailer and rail haul rates, for purposes of comparison. The costs of truck transport were subsequently used to estimate transportation expenses during the analysis of project economics described in the "Results" section. Figures S and T present unit transportation costs for steel and fiber, respectively. The figures also present estimated average California landfill tipping fees as a point of reference. The derivation of the average landfill cost is described in the subsection, "No-Action Disposal Alternative for By-Products."

The transportation costs for truck/trailer transport were estimated primarily based on typical average hourly cost of contracting for truck transport by a third party, and assuming an average vehicle speed of 55 miles per hour. Rail haul costs were estimated based on information from railroad freight companies.

Figure S. Estimated Unit Transportation Costs for Densified Tire-Derived Steel

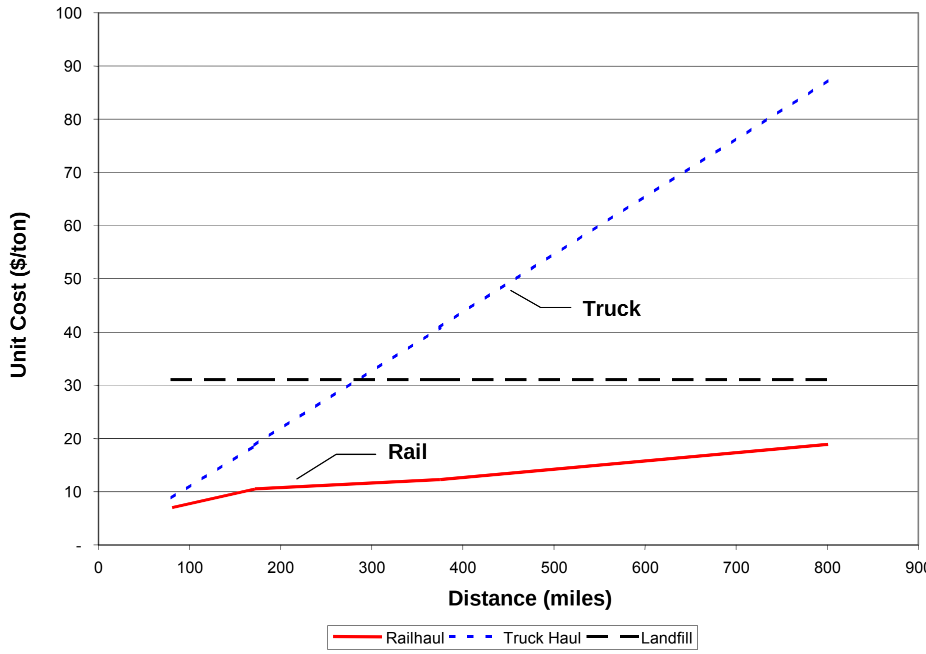


Figure T. Estimated Unit Transportation Costs for Densified Tire-Derived Fiber

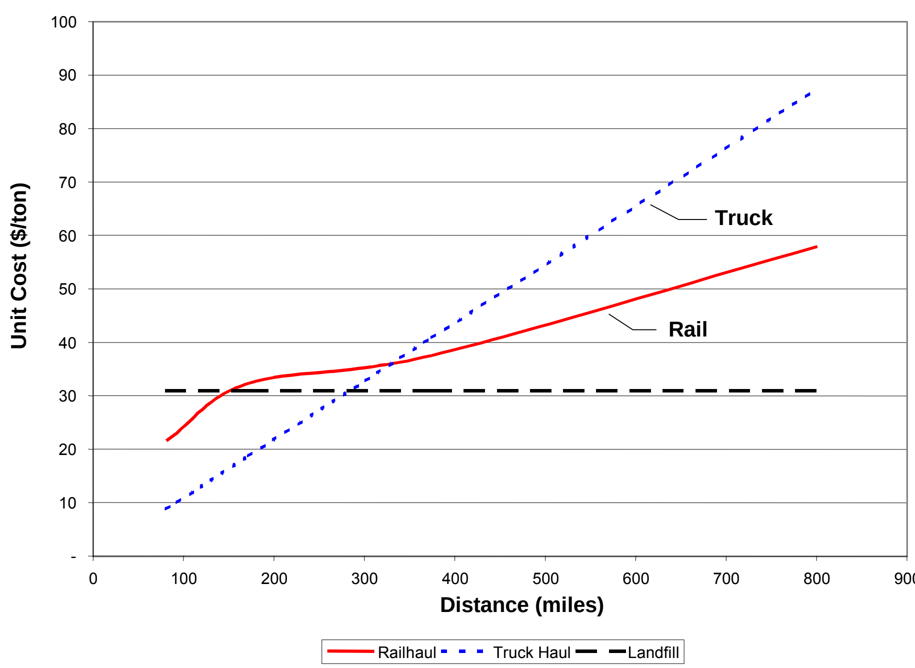
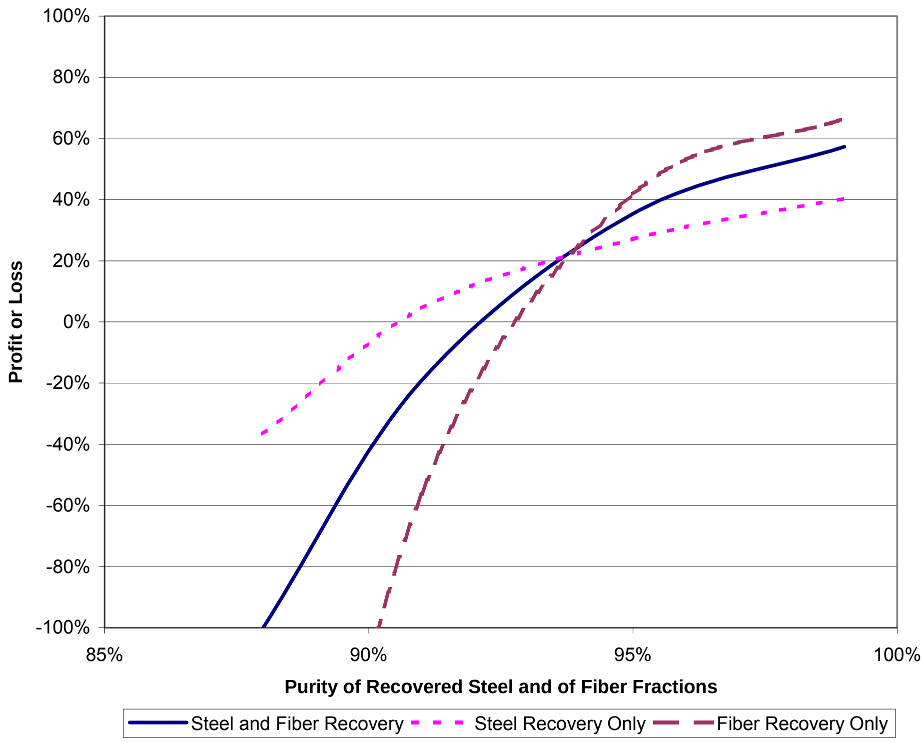


Figure U. Percent Profit as a Function of Equivalent Purity of By-Product Streams
(Base case = 100-mile markets)



Results

The results are presented for recovery and sale of steel and fiber. Additionally, the effects of simultaneous production of steel and fiber are discussed, as well as the results of several other analyses—for example, the no-action alternative (that is, disposal of steel and fiber) and the estimated cost to develop recycling industries for tire-derived steel and fiber.

Steel

The estimated capital cost is about $313,500 to upgrade a "typical" crumb rubber production facility so that it can produce a marketable grade of steel scrap. The estimated annual operating cost is approximately $232,000, including amortization of capital and transporting a steel product 100 miles to market by truck.

The estimated revenues consist of those that would be achieved by the sale of recovered steel and of rubber recovered from cleaning the steel. For the conditions analyzed, the revenues range from $136,000 (for recovered steel with 88 percent purity and 12 percent rubber contamination) to $311,000 (for recovered steel with 99 percent purity and 1 percent rubber contamination). Revenues from sales of crumb rubber comprise 32 to 58 percent of the total product revenues (from 12 to 1 percent rubber contamination, respectively). The remainder is generated by the sale of recovered steel.

The results of the base case analysis for steel beneficiation support a finding that breakeven for beneficiation is about 91 percent pure steel (Figure U) and that purities of 93 percent or more should provide economically attractive margins to processors. Based on this analysis, the pricing of steel must be about $36 per ton in order to break even.

Fiber

The estimated capital cost is about $530,000 to upgrade a "typical" crumb rubber production facility so that it can produce a marketable grade of fiber. The estimated annual operating cost is approximately $193,000, including amortization of capital and transporting baled fiber product 100 miles to market by truck.

The estimated revenues consist of those that would be achieved by the sale of recovered fiber and of the incremental rubber that would be recovered. For the base case, revenues are estimated to be in the range of $53,000 to $575,000, for 88 to 99 percent pure fiber. The rubber removed from the fiber fraction and recovered for sale contributes a substantial portion of the product revenues (in the range of 80 to 30 percent of revenues, respectively, for the above purity values).

The base case analysis indicates profit margins are attractive if rubber contamination is less than 7 percent (that is, greater than 93 percent purity) (Figure U) and if there is sufficient demand for the incremental quantities of recovered fine-mesh rubber. This result implies that the pricing of fiber must be about $73 per ton, or $0.037 per pound, to achieve break-even economics.

The economic analysis for tire-derived fiber recovery and recycling indicates profitability for high-quality fiber if markets are within 100 miles of the facility. However, the fact remains that users may not be located near a processing facility and that the estimates of sale prices for fiber are compromised by the lack of a good statistical database.

Steel and Fiber

Using the above results for beneficiation of steel and of fiber, the cost benefits of joint recovery of steel and fiber can be estimated. In this case, both incremental steel and fiber recovery would be practiced within the same facility. To perform analysis of joint recovery, CalRecovery has assumed that the two incremental processing operations would be essentially independent of one another, although there might be some savings in capital and operating costs if both recovery trains were designed initially as an integrated system. In any event, the estimates of capital and operating costs may be somewhat overstated, but not overly so. To perform the analysis of joint recovery, the costs and revenues for each processing train are summed and analyzed.

The estimated total capital cost of both incremental recovery systems is about $844,000 for the base case, and the estimated operating cost is approximately $379,000, including amortization of capital and transporting recovered products 100 miles to market by truck.

The estimated revenues consist of those that would be achieved by the sale of recovered steel, fiber, and incremental rubber. For the conditions analyzed, the estimated revenues are in the range of $189,000 to $886,000.

The results of the base case analysis for steel and fiber beneficiation support a finding that breakeven for beneficiation is about 92 percent pure steel and fiber, and purities of 94 percent or more should provide economically attractive margins to processors.

Sensitivity to Transportation Distance

The sensitivity of the financial results to shipping distance was investigated in the analysis. Results indicate that for each additional 100 miles of transport distance for by-products, the profit margin decreases by approximately 1 to 10 percentage points.

No-Action Disposal Alternative for By-Products

If by-products are not recycled, they must be disposed. CalRecovery performed an analysis of disposal of steel and fiber residues to provide a basis of comparison for the case of recovery and sale of steel and fiber by-products examined earlier in the report. The objective was to determine the benefit or disadvantage of recycling by-products as opposed to the perceived lower-cost option of managing them, namely disposing of them in a landfill.

For the analysis, it was assumed that the landfill disposal site would be located within 30 miles of the processing facility and that the residues would be transported by third-party haulers operating on a contract basis and using trucks/trailers. It also was assumed that the by-products would be shipped to the disposal site in loose form (that is, the state that they are in when exiting the processing lines, since most facilities would not be densifying residuals destined for disposal).

In terms of landfill cost, an average cost of $31 per ton was used for uncompacted waste, which is approximately the average cost of landfill disposal in California in 2000, as reported by the CIWMB. Values of approximately $30 per ton were also reported by CIWMB in the five preceding years. In 2000, the Board reported that the range of landfill tipping fees was approximately $3 to $85 per ton for uncompacted waste. This analysis assumes that the average cost of disposal reflects that which would be charged for loose steel, fiber, or both -- that is, there would be no surcharges associated with handling or landfilling these particular types of waste because of their properties.

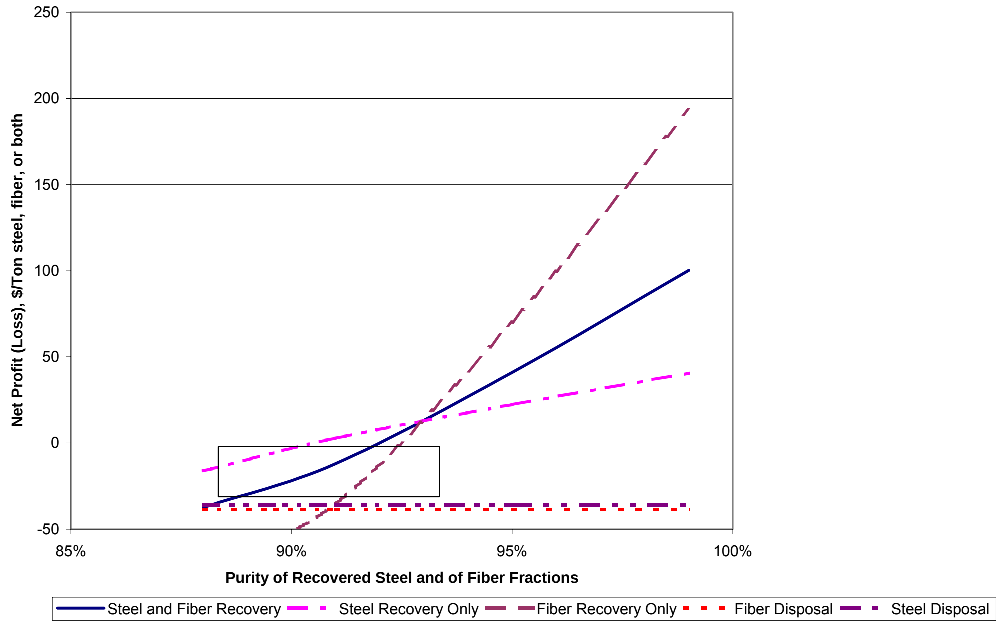
When costs of transportation are added to the landfill disposal cost, the total cost of disposal is approximately $34 to $36 per ton, depending on if the residue is loose steel, fiber, or a mixture.

Comparison of Recycling and Landfill Disposal

The analysis indicates that the economics are favorable for recycling of steel, fiber, or both in comparison to landfill disposal, as long as sufficiently pure by-products can be recovered, as Figure V shows. The data in Figure V reflect the base-case estimates of unit recycling revenues over a range of product purities, versus the estimated average unit cost of the disposal alternative. When considering that regional disposal costs could be as low as about $10 per ton (refer to the rectangular box superimposed on the plot), generally one can say that recycling is feasible only if product purities of at least 89 to 92 percent are achieved. However, while commodity prices for steel and fiber versus purity were modeled as a smooth continuum (for the purposes of estimation), in practice, discontinuities in pricing structure exist. Consequently, it is likely that product purities of 97 percent or more would be required in order to have a sustainable market for steel or fiber. Also, markets can be further away than 100 miles or operating costs could be greater than those estimated, although it is believed that the operating cost estimates are accurate to about +/- 20 percent.

If the fine-mesh crumb rubber cannot be sold, the economics are not as robust those indicated in Figure V.

Figure V. Economics of Recycling By-Products in Comparison to Disposing of Them (Base case = 100 miles to market, 30 miles to landfill)



Steel

Any commercial mini-mill capacity and its associated investment will be large compared to the maximum potential recovery of tire-derived-steel from crumb rubber production of 14 thousand tons in 2002 in California. A new mini-mill needs to be competitive in the world markets and scaled to a capacity of at least 200,000 to 400,000 tons annually. A successful product mix should avoid direct competition with TAMCO (that is, produce products other than rebar).

The estimated capital investment for a new mini-mill is estimated to be in the range of $165 to $248 million dollars, with operating costs (including amortized capital costs) estimated to be in the range of $118 to $170 per ton of capacity. The actual investment could be significantly higher to add processing flexibility, such as direct reduction of iron (+ 20 percent) or finishing operations, such as rebar or thin slab rolling (+ 125 percent). The estimate is based on an analysis by Cyert and Fruehan (Cyert and Fruehan, 1996).

A commercial-scale mini-mill that is able to compete internationally has capacity many times that of the potential tire-derived-steel recovery from California, or all of the western United States. Thus, a more realistic option is to explore ways to encourage TAMCO to invest in the necessary equipment and systems to safely handle and process tire-derived steel. Its incremental investment to safely and economically use tire-derived-steel are unknown, but would be significantly less than the cost of a new plant.

Fiber

To develop a cost estimate for a "representative" fiber recycling industry, two alternative applications were developed and analyzed, since no one use is dominant in the United States or California. The two alternatives are: (1) molding of shipping pallets from polymeric feedstocks, and (2) manufacture of matting from synthetic fibrous materials.

Molded Pallets: Based on information from an entrepreneurial company, the capital investment is approximately $1 million for a facility to manufacture/mold pallets from synthetic polymers, consuming about 3 to 4 million pounds (1,500 to 2,000 tons, respectively) of tire-derived fiber annually in an 80:20 blend with recycled plastics. Polymeric fibers other than tire-derived fiber are required to facilitate processing, to provide the necessary properties to the molded product, or both. The pallet facility would consume between 3.2 and 4.2 million pounds of tire-derived fiber, or 18 to 24 percent of the expected maximum potential 2002 tire-derive fiber recovery. Operating costs, including amortization of capital, are estimated to be in the range of $0.5 to $0.6 per pound.

Production of Mat-Type Product: Mats of synthetic fibers are used in selective applications such as erosion control, automotive compartment barriers (for example, for filler, thermal insulation, and sound deadening), particulate filtration, stuffing for furniture and mattresses, carpet backing, animal blanket, and protective blankets used by furniture moving companies.

There are at least a half dozen methods of forming a fiber mat. The most likely process is needle-punching, which many participants now use. There is a tendency to use needle-punching in developing new markets because of its flexibility in accepting a variety of feedstocks and in manufacturing a variety products (compared to high-speed dedicated (that is, single product) lines), because older equipment with poorer product quality may be sufficient to promote a new application. The biggest downside issues are a global oversupply of needle-punch capacity and many offshore producers that could lead to increased product imports on the West Coast.

The estimated 2002 investment cost is in the range of $3.5 to $4.5 million for a needle-punching operation consuming 2 to 5 million pounds of straight tire-derived fiber annually. The estimated operating costs, including amortization of capital, are in the range of $0.85 to $1.24 per pound of fiber.

Chapter 6. Conclusions and Recommendations

A number of key conclusions and recommendations were identified as a result of the analysis. This chapter describes the conclusions and recommendations under their separate headings below.

Conclusions

Background and General

1. There are many waste tire processing facilities in the United States and California. Their primary product is recovered natural rubber and synthetic rubber (that is, synthetic polymeric compounds) materials that are marketed in bulk as a variety of product grades—for example, tire chips or crumb rubber. On the other hand, very few waste tire processors market the steel, and even fewer processors market the fiber produced as by-products of the rubber recovery operations.

2. The supply of tire-derived steel and fiber in California is now driven by the market demand for, and the production of, crumb rubber, non-crumb rubber products, and TDF. Existing processors in California and elsewhere have the ability to increase steel and fiber production. Thus, supply of by-products should not limit market demand for these by-products in California.

3. California markets for tire-derived steel and fiber, like those in other U.S. regions and in other countries, are at an early state of development. Thus, although growth may be rapid once new applications/markets are developed or customers are identified, at present only a few commercialized applications, such as scrap steel and fiber TDF, offer the "immediate" possibility for expanded growth. Even in more established markets for tire-derived steel and fiber, finding new customer interest and qualifying materials takes time and resources. Fully developing markets for tire-derived steel and fiber is thus likely to require a number of years.

4. The study estimates that approximately 30 to 35 million waste tires were generated in California in 2002. Annual generation is projected to be 34 to 39 million tires in 2007.

5. Approximately 61,000 tons of tire-derived steel could have been recovered in California in 2002 if all waste tires had been processed and the steel recovered. An estimated 14,000 tons of steel could have been recovered if all of the steel had been recovered as a by-product of crumb rubber production in California in 2002. Either of these quantities of potentially recoverable steel is less than 1 percent of the estimated 44 million-ton scrap steel market in California.

6. A maximum quantity of approximately 39,000 tons of tire-derived fiber could have been produced in California in 2002, assuming 100 percent recovery. Based on only crumb rubber production in California in 2002, and assuming 100 percent recovery, about 9,000 tons of fiber could have been recovered.

7. In California and elsewhere, much of the tire-derived steel and fiber has been landfilled due to one or more of the following reasons: (a) its quality does not meet market requirements; (b) distance to market is too great; (c) the marketplace is undeveloped; (d) attempts to demonstrate applicability have failed; (e) standards for tire-derived steel and fiber have been lacking; (f) independent, low-resource processors do not have the financial resources needed

to sustain development of new markets; and (g) steel and fiber are by-products of rubber recovery in tire processing, and driven by the recovery of rubber rather than the commercial requirements of steel and fiber end uses.

8. There is a dearth of information available in the public domain related to fiber and steel produced as a result of processing waste tires. Some general information was found in the literature search related to the composition of fiber and steel used in the manufacture of tires. However, little if any data were found on the specific characteristics of fiber and steel by-products, such as weight percent contamination in the form of rubber, particle size distribution, chemical composition, etc.

9. Very few market specifications for tire-derived steel or fiber were found during the performance of study (the Institute of Scrap Recycling Industries issued a set of specifications for tire-derived steel in May 2003 – see Appendix E).

10. The steel belting and steel bead used in tires have industry-wide, specified characteristics, but the marketability of the steel is sometimes compromised by the recovered mix of steel, composition of the steel, and contamination of the steel by materials such as rubber and fiber.

11. The West Coast of the United States currently has only one steel mill that can accept and use the quality of steel recovered from waste tires. That mill (TAMCO) was processing only bead steel at the time of the industry survey due to problems concerning energy costs. Markets for tire steel are therefore very limited for tire steel produced as a result of processing waste tires in California.

Industry and Market Situation

Steel

1. Tire-derived steel is marketed successfully by a number of processors in the United States and internationally. However, in California, markets for this material currently appear to be limited. This is due to ignorance of potential users of the availability of tire-derived steel and to the poor quality of tire-derived steel currently produced. Other factors include a limited number of users or lack of users within an economic radius or a combination of these factors. In California, tire-derived steel could be used or marketed successfully if the steel is of 95 percent quality or better. This level of quality is technically attainable, as evidenced by data reported by waste tire processors outside of California.

2. Even under liberal estimations of growth in supply, the available 2007 California market for steel scrap is more than three times the amount that can be produced from processing waste tires. However, the large size of the potential market will be of little relevance until tire-derived steel can be delivered to the market in an acceptable form (for example, with low rubber contamination) and with profitability that is commercially feasible for California processors. For the California market to increase, tire-derived steel will need to satisfy customers' purity, safety, operational, and other requirements. While the quality of tire-derived steel improves over time, the Pacific Northwest, Mexico, and other export markets probably offer the best opportunities for absorbing the increasing amounts of tire-derived steel in California.

3. Until the rubber content of tire-derived steel is reduced, the steel is densified, conveniently packaged, or a combination of these, tire-derived steel will be one of the first grades of scrap steel resources to be dropped when markets weaken. With better quality, however, tire-derived steel can participate in the normal supply and demand swings, with adjustments in price, inventories, and net exports made to reach equilibrium.

4. In general, the technology exists to produce tire-derived steel conforming to marketable standards, both in the case of bead and belt steel. However, performance data for cleaning equipment are generally not publicly available. Thus, processors are at a disadvantage when trying to estimate yields and quality for purposes of assessing incremental economic benefit and specific market opportunities.

5. Tire-derived steel is a commodity that has a well-defined market, namely the ferrous scrap market. This market has a well-established network of middlemen—such as scrap recyclers and blenders—that serve the users, namely steel mills and foundries. The market lacks standards for tire-derived steel, with the exception of the specifications for tire-derived steel issued by ISRI. The more important market considerations for use of tire steel by steel mills and foundries are: level of rubber contamination, coating metallurgy, and packaging (for example, some users want product compacted to specific bulk densities, bundled to particular dimensions, or both).

Fiber

6. The market for tire-derived fiber is very weak. The principal commercial product is fiber TDF fuel, which is a substitute for TDF and other hydrocarbon fuels. High energy prices should encourage the use of a low-sulfur, high-BTU fuel. However, the California markets for TDF have declined significantly since 1995. Other known non-fuel outlets are mainly in the developmental stage and regionally located. Most potential non-fuel markets for fiber require it to be metal-free and that it have low or no rubber contamination. Thus, growth will be very modest until cleaner fibers are available for sale. Secondary market requirements such as fiber length or other attributes will also affect market development. In the meantime, volume applications in low-end applications such as composites and asphalt, if they can be found, may offer hope of future growth.

7. As opposed to the situation with tire-derived steel, tire-derived fiber has only a few isolated end uses with no well-established niche, regional, or global markets. This situation is due to a number of factors, including lack of documentation of the characteristics of the fiber, lack of types of uses and user-defined feedstock specifications, and lack of user knowledge of and experience with the fiber in specific applications. Another potential factor may be the ability of processors to technically achieve the specifications required by the markets. User specifications for tire-derived fiber have not been formalized in the industry as a function of uses. Particular hurdles on the technical side appear to be: (1) achieving marketable quality and physical properties of recovered fiber, and (2) lack of ability to segregate fiber resins by type.

8. The potential uses and marketability of fiber are a strong function of its composition. The composition varies with the age of the tires, which is reflective of the historical improvements in tire construction, and will vary in the future due to competitive pressures in the tire industry to manufacture tires that have improved technical performance and lower production costs. Additionally, waste tire processing facilities in general do not have methods of controlling the types and ages of waste tires that are accepted at their facilities. Other important factors pertinent to marketability are purity of recovered fiber and type and extent of crimp (that is, bent fibers).

9. The state of the marketplace for mixed fiber feedstocks is that specifications are negotiated between supplier and user. These are based almost exclusively on price and properties as produced. No organization is researching or developing specifications that are applicable to tire-derived fiber, which would lend some uniformity to the marketplace. Since there is no

commercial history of use of tire-derived fiber, no chain of supply has been established. Consequently, the onus for finding markets rests entirely with processors.

10. Since no commercial markets have been developed in the United States for tire-derived fiber other than some very localized ones, most processors in California dispose of the material. Both technical innovation and market development are indicated by the survey as necessary for promoting use of tire-derived fiber in California.

Cost Benefit

1. An economic analysis indicates that in California recycling of steel can be cost effective in comparison to landfill disposal. In fact, the profit margins of steel recycling could be quite attractive to processors. There is good evidence (from the market analysis task) that a market exists or would exist for steel of purity greater than about 97 percent. Consequently, market risk to processors appears manageable. The chief impediment to steel recovery and recycling is capital cost, on the order of several hundred thousand dollars, and negotiating a firm steel purchase agreement to minimize the risk associated with the required capital outlay.

2. The situation is similar in the case of recovery and recycling of fiber. However, the risks are substantially greater than those associated with steel recovery. Lack of markets in California for fiber from waste tires makes the accuracy and precision of the revenue projections debatable. CalRecovery could estimate the conditions based only on the scant history outside of the state. Evidence is that tire-derived-fiber quality would have to be in the range of 98 percent or greater purity in order to approach the quality that would command an assured market. Thus, substantial market risk exists in the case of tire-derived fiber, which puts the required capital outlay (an estimated one half million dollars) at substantial risk. Also, the capital equipment needed to clean the fiber to high quality lacks operating history and availability of performance data. Thus, the accuracy of capital and operating costs are compromised and represents additional risk to processors.

3. A substantial portion of the profit potential of recovering steel, fiber, or both is derived from the recovery of crumb rubber, as a by-product of cleaning both the steel and fiber to high-purity grades. On a unit basis, crumb rubber grades sell at prices that are typically five to ten times greater than those that high-quality by-products could or would likely command in the marketplace. However, the California demand for this additional recovered finely sized crumb rubber is untested.

Recommendations

Steel

1. Commercially viable processing technology likely exists to produce high-quality tire-derived steel in California. This could circumvent the generally low-quality steel currently produced and the lack of market demand. In practice, tire processors may have to add equipment to further clean and package steel to user specifications. Capital equipment funding assistance would serve to bridge the gap between procurement and installation of equipment and on-set of product revenues as a consequence of steel sales.

2. Currently, data on tire-derived steel characteristics are lacking and not publicly available. This adversely affects the ability of designers, operators, and end users to plan and implement sound, cost-effective tire wire recycling. A need exists for incentive programs to collect and disseminate data on recovered tire wire quality and on the performance of steel cleaning equipment and systems.

3. The Board could assist in improving processor-user communication, which could help develop markets for high-quality tire-derived steel. Funds to sample and market various forms of tire-derived steel in California could substantially improve the dialog among processors, material brokers, and end users. Capital improvement loans or grants could assist processors in the purchase of steel recovery systems or of system components that would generate high-quality steel products.

Fiber

4. The issues and barriers confronting tire-derived fiber recycling in California are many. Most are generated in one form or another by the fine mixed resin composition of recovered tire-derived fiber and its current poor purity. Mixed resin tire-derived fiber is a low-end commodity and has thus far found only isolated, opportunistic market niches. The fuel market (for fiber TDF) is insensitive to the mixed resin composition. This use is very small in California, probably because of the lack of supplies of economic tire-derived fiber and lack of marketing experience in the state. Based on experience elsewhere in North America, concerted efforts to divert tire-derived fiber to fuel markets appear to be warranted.

5. The scarcity of data related to recovered fiber characteristics deters both processors and potential users of the data required to judge applications for tire fiber. Data gathering spurred by Board incentives would substantially assist producer/user communication and market development.

6. The entrepreneurial waste fiber and textile companies are some of the best sources of ideas for the use of tire-derived fiber. However, they have yet to be exposed to the material and are therefore handicapped in developing potential applications. Scrap metal dealers offer a similar market development role for tire-derived steel. A sampling program is recommended for consideration, either by individual processors or through regional or national cooperative programs.

7. The commercial development for tire-derived fiber remains in an early stage with no product standards. Single processors may not have resources to push commercial development efforts without incentives or collaborative efforts. Funding by the Board could assist individual processors and/or users and broaden the currently narrow lines of communication between them.

Steel and Fiber

8. Generally, communications among buyers and sellers in the tire-derived by-product marketplace need to be improved. Given their lack of regular commercial dealings, processors face a difficult task in developing new outlets for tire-derived by-products. Compounding this issue is their current practice of having waste haulers remove and resell materials—a practice that does not directly develop the processors’ markets. Processors should thus consider assuming a greater role in the sale of steel and fiber.

9. Market success is tied to providing a product that meets the needs of customers. Having flexibility in processes to tailor the characteristics of tire-derived steel and fiber is vital to market development with these materials. Processors generally lack engineering staffs, multiple plants, duplicate equipment lines, and other forms of processing flexibility. Their limited resources make it difficult to: (a) identify customers and their needs, and (b) adjust steel and fiber quality to meet those needs. Many processors contacted during the study said that they could not justify the effort, resources, and investment required to pursue an uncertain market. Thus, market development for these by-products will progress at a much slower pace than it might if the Board facilitated market development for steel and fiber. The

Board should foster and facilitate communication between tire processors and potential markets. This process should include monitoring development of standards, and facilitating development of by-product specifications organizations that set consensus standards, such as ISRI and ASTM.

10. The Board should consider that a modest level of incentives or program efforts would probably stimulate substantial recycling of tire-derived steel in the short term. On the other hand, a successful development program to substantially increase recycling of tire-derived fiber would likely require a long-term commitment and a multi-faceted approach due to the number and types of barriers involved.

Abbreviations

ASTM	American Society for Testing and Materials
Caltrans	California Department of Transportation
CIWMB	California Integrated Waste Management Board
DOF	California Department of Finance
EU	European Union
GVW	gross vehicle weight
ISRI	Institute of Scrap Recycling Industries
PTE	passenger tire equivalent
RMA	Rubber Manufacturers Association
TDF	tire-derived fuel
UK	United Kingdom
VMT	vehicle miles traveled

Glossary of Terms

Additive	A minor constituent of tires added to confer some required characteristic(s).
Aromatic polyamide	Type of synthetic polymer used in tire construction; a group of chemical compounds containing aromatic rings—for example Kevlar®.
Bead	Portion of mounted tire that is shaped to fit the wheel rim; composed primarily of a circular cord (assembly) of strands of high-tensile steel wire
Bead steel (or wire)	Steel wire contained within the tire bead.
Belt	An assembly of fabric, wire, or both used to reinforce the tire tread.
Belt steel (or wire)	Steel wire located with the fabric layer immediately below the tread.
Bias tire	Tire assembly composed of two or more plies that are positioned at 30 to 45 degrees to the centerline of the tread.
Body	Tire assembly except for tread and sidewall rubber.
Body steel (or wire)	Steel wire contained within the plies.
Component	Part of a whole or mixture; for example, a type of material, such as natural rubber, is a component of waste tires.

Composition	The makeup or constitution of a whole or mixture; collectively, the individual components of a whole or mixture; commonly expressed as a percentage of the whole.
Constituent	Same meaning as “component.”
Cord	An assembly of twisted strands of fibers composed of plastic resin(s), such as polyester or rayon, or steel, that provides tires and belts with strength.
Crumb rubber	Finely sized rubber product recovered from waste tires.
Fiber	Natural or synthetic fiber used in tire construction.
Nylon	Type of synthetic polymer used in tire construction.
Plies	The fabric layers that compose the cord body of the tire.
Polyester	Type of synthetic polymer used in tire construction.
Polymer	A long-chain chemical compound composed of many smaller, identical molecules.
Radial tire	Tire constructed such that the plies underlie the tread at 90 degrees.
Rayon	Type of synthetic polymer used in tire construction.
Rubber	Natural or synthetic rubber.
Sidewall	Portion of tire assembly between the edge of the tread and the bead.
Tire-derived fiber	Fiber separated from waste tires as a consequence of processing.
Tire-derived fuel (TDF)	Materials having fuel value recovered from waste tires (most commonly the rubber materials, but also can include fiber).
Tire-derived steel	Steel separated from the other components of waste tires as a consequence of processing.
Tread	Portion of tire that contacts the road surface.
Vulcanization	The thermal process (under pressure) that chemically links rubber compounds and polymers together, forming an elastic mixture.
Waste tire	A tire that is no longer mounted on a vehicle and is no longer suitable for use as a vehicle tire due to wear, damage, or deviation from the manufacturer's original specifications. A waste tire includes a repairable tire, scrap tire, and altered waste tire, but does not include a tire-derived product, crumb rubber, or a used tire that is organized for inspection and resale by size in a rack or a stack.

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Recyclers.Net (portal to salvage recycling industry) (www.recyclers.net/)

Textile FiberSpace (www.textilefiberspace.com)

Thomas Register (www.thomasregister.com/)

Yahoo search engine (www.yahoo.com)

California Portland Cement Company (www.calportland.com)

Used Tyre Working Group (www.tyredisposal.co.uk)

U.S. Environmental Protection Agency (www.epa.gov)

Kirk-Othmer Encyclopedia of Chemical Technology (www.mrw.interscience.wiley.com/kirk/index.html)

Various state recycling and tire waste authorities

California Integrated Waste Management Board (www.ciwmb.ca.gov)

Appendix A.
Publications and Web Sites Used in Literature Search

(Research of many of the items in this appendix resulted in examination of sources listed in the bibliography.)

Publications

BioCycle (www.jgpress.com/biocycle.htm)

MSW Management (www.forester.net/msw.html)

Public Works (www.pwmag.com)

Recycling Today (www.recyclingtoday.com)

Resource Recycling (www.resource-recycling.com)

Scrap Tire News (www.scraptirenews.com)

Web Sites

California Integrated Waste Management Board (www.ciwmb.ca.gov)

Entech, Inc. (www.4entech.com/)

Allstate Tire Recycling (http://www.allstatetire.com/)

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British Rubber Manufacturers' Association Ltd. (www.brma.co.uk/)

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Global Recycling Network (www.grn.com/)

Global Tire Recycling of Sumter County, Inc. (www.gtrcrumbrubber.com/)

International Solid Waste Organization (www.iswa.org/)

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EDINA–CAB Abstracts (http://edina.ac.uk/cab/)

EDINA Ei Compendex (http://edina.ac.uk/compendex/)

EDINA Inspec (http://edina.ed.ac.uk/inspec/)

Environment Agency, R&D Dissemination Centre (UK) (www.environment-agency.gov.uk/science/?lang=_e)

BIDS (Bath Information and Data Services) (http://www.bids.ac.uk/)

DEFRA (Department for the Environment, Food, and Rural Affairs) (UK) (www.defra.gov.uk/)

Department of Trade and Industry (UK) (www.dti.gov.uk/)

ESDU (Engineering Sciences Data Unit) (www.lib.gla.ac.uk/Resources/Databases/esdu.shtml)

European Environment Agency publications (European Union) (www.eea.eu.int/)

European Tyre Recycling Association (www.etra.eu.com/)

Federal Environmental Agency publications (Austria) (www.ubavie.gv.at/index.htm)

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FIZ–WEMA (FIZ-Werkstoffe/Materials) (www.fiz-technik.de/en_db/d_wema.htm)

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Appendix B.
Waste Tire Processing Facilities and Technologies Compiled From Literature Search, In Addition to Those Noted in Tables 10 and 11

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Alruba Manufacturing Co. Ltd., Derby, UK						Produce variety of finished crumb rubber products, including REBOUND soil amendment, SportsTurf RubberStuff playground pads, SafetyPlay pour-in surface, RubberStuff mulch rings, rubber/plastic landscape timbers, park benches, PERMA-FLEX topping, etc.	Airfield Industrial Estate Derby Road Ashbourne Derby UK DE6 1HA Mr Johnson 44-1335-342994		www.tyredisposal.co.uk (Select "Recycling Companies" and search by "Alruba.")
American Rubber Technologies, Inc., Jacksonville, Fla.						Perma Lumber Landscape Timbers. Make REBOUND Turf Management System.	PO Box 6548 Jacksonville, FL 32236 Tiffany Hughes 800-741-5201		www.rubber.com/rubber/trade/index.html *Scrap Tire News*, June 2002, p. 13. *Scrap Tire News,* August 2002, p. 18.
American Surface Technologies, Scottsdale, Ariz.			Commercial	Tires		"Safety Play": ready mixed pre-packaged rubber surfacing, similar to concrete.			Taylor, Brian, "On a Roll," *Recycling Today*, October 1999, pp. 28–36.
Arthur Schofield Inc., Lancaster, Mass.	Shredding			Tires	Shreds				Humphrey, Dana and Blumenthal, Michael, "Civil Engineering Applications of Scrap Tires: An Emerging Market," *Resource Recycling*, December 1998, pp. 26–30.
Ashgrove Cement, Inkom, Idaho/ Durkee, Oreg.	Burns tires for TDF	1,000 tires/day		Tires		TDF for cement kilns			Farrell, Molly, "Building Sustainable Recycled Tire Markets," *BioCycle*, May 1999, pp. 50–52.

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
B.A.S. Recycling, Inc., San Bernardino, Calif.		3,500,000 tires/yr		Tires	Crumb rubber		1400 N H Street San Bernardino, CA 92405 Mike Harrington (909) 944-4155		Phillips, Mark, "California Moves Aggressively in Managing Scrap Tire Problem," *Recycling Today,* October 1998, pp. 34-46.
Beven Recycling (UK) Ltd, Gloucestershire, UK	Pyrolysis						Cotswold Innovation Centre Rissington Business Park Cheltenham Gloucestershire UK GL54 2QB Herbert Beven or Ann Jervis 44-1451-812210	May be a lead into how waste tire steel is being marketed.	www.tyredisposal.co.uk (Select "Recycling Companies" and search by "Beven Recycling.")
Black Hawk County Landfill, Waterloo, Iowa		3,000,000 tires		Tires		Uses 3,000,000 tires in leachate collection system			"Iowa Continues to Search for Tire Markets," *BioCycle,* September 2001, p. 73.
Canglobe Development, Inc., Edmonton, Alberta, Canada	Patented devulcanization of ground tire rubber using "sulfur oxidizing chemolithotropic microorganisms"								*Scrap Tire News,* August 2002, p.4
Castle Cement, Lincolnshire, UK	Energy recovery	12,000 metric tons chipped tires per yr					Ketton Nr. Stamford Lincolnshire UK PE9 44-1780-721316 www.castlecement.co.uk		www.tyredisposal.co.uk (Select "Recycling Companies" and search by "Castle Cement.")

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Coalite Tyre Services, Derbyshire, UK	Pyrolysis	Initially, 15,000 metric tons/yr					PO Box 21 Chesterfield Derbyshire UK S44 6AB Nick Ross 44-1246-82518		www.tyredisposal.co.uk (Select "Recycling Companies" and search by "Coalite Tyre Services.") *Scrap Tire News,* November 2001, p. 12.
Composite Particles, Inc., [now Inhance Group, with Fluoro-Seal, Houston, Tex.]	Surface modification—finely ground rubber particles derived from waste tires are exposed to reactive gases, causing permanent chemical change to the rubber's outer molecular layers and allowing it to bond with polyurethane, latex, and other polymers.	8,000,000 lb/yr	Commercial (1993)	Tires	Treated crumb rubber		16360 Park Ten Place, Ste. 325 Houston, TX 77084 Bernard Baumann (281) 600-1255 bbauman@fsicorp.com		Blumenthal, Michael, "Growing Markets for Scrap Tires," *BioCycle,* October 1997, pp. 53-55.
Duralay Ltd, Durham, UK		13,000 metric tons of tires/yr					Littleburn Industrial Estate Langley Moor Durham UK DH7 8HJ 44-1706-213131 www.duralay.co.uk		www.tyredisposal.co.uk (Select "Recycling Companies" and search by "Durlay.")

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Emanuel Tire, Baltimore, Md.	Shredding			Tires	Wire-free tire chips		(800) 445-1887 emantire@aol.com, Norman Emanuel ; (410) 947-0660		Powell, Jerry, "The Hottest Trends in Tire Recycling," *Resource Recycling*, December 1996, pp. 14–20. *Scrap Tire News*, August 2002, p. 18.
EnTire Recycling, Nebraska City, Nebr.	Uses system made and designed by ShredTech, Cambridge, Ontario, as well as cryogenics.	2,000,000 tires/yr		Tires	Crumb rubber				Taylor, Brian, "Same Tired Story?" *Recycling Today*, May 1999, pp. 33–42.
Entire-Enviro, Inc., Youngstown, Ohio							1130 Performance Place Youngstown, OH 44502 Jesse J. Salomone (330) 747-8473	Sheets are sold to die-cut industry to make livestock trailer walls, truck-bed liners, landfill caps.	www.rubber.com /rubber/trade/index .html
Envirotech Extrusions, Richmond, Ind.		4,000 tons/yr		Tires	Rubber sheets				Powell, Jerry, "The Hottest Trends in Tire Recycling," *Resource Recycling*, December 1996, pp. 14–20.
Euretec Inc., Tustin, Calif.							(714) 508-1470	Accepts only bias OTR tires and not radials—radials have too much steel and are harder to process. All leftovers are put in shredder so there is no waste.	*Scrap Tire News,* April 1998 (ITRA Exhibition list)

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
F&B Enterprises, New Bedford, Mass.	Shredder, stamps out sections.	15,000 tires/day		Tires	Chips, rubber sections	Wear pads for buckets and snow plows, rubber rollers for the bottom of large fishing nets, boat bumpers, pads and fenders, dock piling protectors.	Tom Ferreira, owner		Phillips, Mark, "Land of the Giants," *Recycling Today*, March 1996, pp. 48–54, 84.
Freedom Tire Inc. (FRT), Anaheim, Calif.							708 E South Street Anaheim, CA 92805 (714) 991-4788	FRT plans to build/operate pyrolysis plants in Calif. and Tex.	
Georgia Tire Recovery, Griffin, Ga.							2026 Tallwood Pl. Griffin, GA 30223 Rick Rickerson (770) 228-0479	Includes place for listings of waste tire bead wire, available or wanted, but nobody is listed as buying or selling them.	www.rubber.com/rubber/trade/index.html
Global Rubber, Inc., King of Prussia, Pa.		75,000,000 lb of rubber/yr					Mike Hovespian, President		*Scrap Tire News,* May 2002, p. 8
Global Tire Recycling of Sumter County, Wildwood, Fla.		2 million tires, 16,000 tons crumb rubber/yr					1201 Industrial Drive Wildwood, FL 34785 (352) 330-2213 www.gtrcrumbrubber.com		*Scrap Tire News,* August 2002, p. 16.
Golden By Products Inc., Ballico, Calif.							13000 Newport Road Ballico, CA 95303 (209) 381-1082		www.losbanosenterprise.com/printer/article.asp?c=7886
Goodluck Ventures Steel Belted Radial Fencing, Beggar, Saskatchewan, Canada						Animal fencing strips with steel belts intact	(306) 948-2848		*Scrap Tire News,* March 1998, p. 18

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Goodyear Tire and Rubber Co, Akron, Ohio	Devulcanization using a solvent that extracts polymers from rubber without degrading it.		In lab stage	Tires	Polymers		Larry Hunt, Ron Kovalak, co-inventors; Ron Dill, director of analytical and materials testing		Taylor, Brian, "On a Roll," *Recycling Today*, October 1999, pp. 28–36.
Granutech-Saturn Systems Corp, Grand Prairie, Tex.							(972) 790-7800	Bagged product sells in Lowe's and Home Depot stores	*Scrap Tire News,* March 2002, p. 24
Green Edge Enterprises LLC, St. Louis, Mo.	Colorizes shredded vulcanized tire chips to popular mulch colors.		Commercial	Tires		Shredded tire mulch product with colors: "Rubberific Mulch"	Lee Greenberg	Purchased Unlimited Tire Technologies of Azusa, Calif., which processes more than one million tires per year.	Taylor, Brian, "On a Roll," *Recycling Today*, October 1999, pp. 28–36.
GreenMan Technologies, Inc., Lynnfield, Mass.	Shredding—a multifaceted company in tire recycling.	21,000,000 tires/yr		Tires	Crumb rubber, TDF		Robert H. Davis, President/CEO Jim Dodenhoff (800) 526-0860		Taylor, Brian, "Same Tired Story?," *Recycling Today,* May 1999, pp. 33–42.. *Scrap Tire News*, January 2002, p. 14
Holnam Inc, Mason City, Iowa	Uses TDF			Tires		TDF as supplemental fuel for cement kiln. Ash used in manufacturing.			"Iowa Continues to Search for Tire Markets," *BioCycle*, September 2001, p. 73.
Ikarus-Recycling GmbH, Walterhousen, Germany	Cryogenic recycling						Gerhard Krieg 49-3546-1827-89	Used in a critical height test of loose-fill, wire-free, playground surface material.	*Scrap Tire News,* January 2000, p. 14

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
J.P. Routhier & Sons, Littleton, Mass.	Shredding			Tires	Shreds				Humphrey, Dana, Blumenthal, Mike, "Civil Engineering Applications of Scrap Tires: An Emerging Market," *Resource Recycling*, December 1998, pp. 26–30.
JaiTire, Denver, Colo.	Crown III crumb rubber		Commercial			Crown III is sprinkled on top of grass to reduce compaction, insulate roots and stems, and aid in aeration and drainage	Cornelius (Corny) Snyder, owner		Phillips, Mark, "The Trouble With Tires," *Recycling Today*, March 1998, pp. 78-84,89-92,96-100.
Jeng Yuan Reclaimed Rubber, Selangor, Malaysia		12,000 metric tons annually					No. 22, 2nd Floor Jalan Tiara Dua Bandar Baru Klang 41150 Kland Selangor, Malaysia 41150 Ben Lian Chee Meng 603-344-7628		www.rubber.com/rubber/trade/index.html
Mid-Continent Resource Recovery, Wichita, Kans.	Makes product from recovered rubber		Commercial	Tires		Prefabricated masonry panels for use as patio and swimming pool decking and as welcome mats			Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18-27.
Midway Tire Disposal/ Recycling, Fountain, Colo.		4,500,000 tires per year					Vernie Houtchens (719) 382-3020		www.rubber.com/rubber/trade/index.html
Murfitts Rubber Industries Ltd., Cambridgeshire, UK		50,000 tons per year					Barry Stocker		*Scrap Tire News*, May 2002, p. 20.

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
National Feedscrew, Massillon, Ohio	Devulcanization			Tires	Virgin rubber				Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18–27.
National Recycling Company, Inc., Homer, N.Y.							P.O. Box 6 Homer, NY 13077-0006 Edmond Roelen (607) 749-3849	Makes crumb from whole tires or shredded chips they buy from first-level processors.	www.rubber.com/rubber/trade/index.html
National Rubber Baker Materials, South Bend, Ind.				Tires	Crumb rubber		Jerry Holland		Phillips, Mark, "Land of the Giants," *Recycling Today*, March 1996, pp. 48–54,84.
Oxford Recycling, Inc., Englewood, Colo.		50,000 tires per year					John F. Kent (303) 762-1160		www.rubber.com/rubber/trade/index.html
PCC Group Inc., Pomona, Calif.		6,000,000 tires per year					163 University Parkway Pomona, CA 91768 Don Johnson (909) 869-6133		www.rubber.com/rubber/trade/index.html
Potlach, Lewiston Idaho	Burns tires for TDF at pulp and paper mill.	5,000 tires/day		Tires		TDF for Potlach paper mill			Farrell, Molly, "Building Sustainable Recycled Tire Markets," *BioCycle*, May 1999, pp. 50–52.
Pouroutos Ergoliptiki Ltd, Limassol, Cyprus							2 Acropoleos St. Limassol, Cyprus 3013 Costas Pouroutides 357-5-561860	Partnership with American Tire Recyclers	www.rubber.com/rubber/trade/index.html

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Praxair, Danbury, Conn.	Cryogenic grinding			Tires	Crumb rubber (80 mesh or smaller)				Phillips, Mark, "The Trouble With Tires," *Recycling Today,* March 1998, pp. 78–84,89–92,96–100.
Proco Company, Fairfax, Va.							5533 Wiford Ct. Fairfax, VA 22032 Bill Elomari (703) 503-2211	Detailed report on handling of waste tires in UK, Europe, and North America.	www.rubber.com/rubber/trade/index.html
R-B Rubber, McMinnville, Oreg.	Makes products from crumb rubber		Founded in 1985, went public in 1995	Tires		Rubber mats, horse stall flooring			Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18–27.
Recovery Technologies Group, Eliot, Maine							Martin Sergi	Holds patent to proprietary cryogenic crumb rubber technology (Reclaprocessor). The company says the efficient use of cryogenic nitrogen reduces the requirement for electricity and generates a cost and revenue advantage compared to traditional size reduction methods.	*Scrap Tire News,* June 2002, pp. 1, 14.

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Recycle Direct, Pyle Bridgend, UK							Unit 4, Village Farm Rd Village Farm Ind est Pyle Bridgend UK CF336BL Nigel Davies 44-1656-744422	Product has an antibacterial, antifungicide and fire-retardant additive.	www.rubber.com/rubber/trade/index.html
Recycled Rubber Resources, Huron, Ohio	Coats rubber with colorful, nontoxic material through a continuous feed system. Steel not removed from purchased shredded tires is removed using an earth drum.		Commercial	Tires		Playground fill, horse arenas, soil amendment			"Marketing Tire Shreds as Playground Cover," *BioCycle*, March 1998, pp. 45–47.
Recycling Technologies International LLC, Hanover, Pa.		More than 65,000,000 lb/yr							*Scrap Tire News,* August 2001, p.1.
Royal Mat, Beauceville, British Columbia, Canada		3,000,000 tires/yr				Rubber mats for horses	Jaques Poulin, president www.royalmat.com	Includes listing of many rubber companies, information on tire composition, 19-page report from Scrap Tire Management Council.	*Scrap Tire News,* May 2002, p.5.
Rubber Technology International							Barbara Young (323) 268-6842	Rubber composite makes products stronger, more impact resistant, and longer-lasting.	www.rubber.com/rubber/trade/index.html
Rumber Materials Inc, Munster, Tex.	Mixing crumb rubber with scrap plastic to make rubber composite.	650 tons/yr		Tires		Rumber composite buckets, highway signs, livestock feeders, plastic pallets, trailer bed floors, dumpster, and garbage pail lids.	J'Lynn Hare, general manager, Harold Fischer, president and CEO.		Taylor, Brian, "Same Tired Story?" *Recycling Today*, May 1999, pp. 33–42.

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Sapphire Energy Recovery Ltd (Lafarge Cement UK), Staffordshire, UK	Energy recovery	45,000 metric tons chipped tires/yr					Cauldon Works Waterhouses Nr. Stoke on Trent Staffordshire UK ST10 3EQ www.cement.bluecircle.co.uk		www.tyredisposal.co.uk (Select "Recycling Companies" and search by "Lafarge Cement.")
Sapphire Energy (Lafarge Cement UK), East Lothian, UK	Energy recovery	28,000 metric tons chipped tires/yr					Dunbar Works Dunbar East Lothian UK EH42 1SL www.cement.bluecircle.co.uk		www.tyredisposal.co.uk (Select "Recycling Companies" and search by "Lafarge Cement.")
Sapphire Energy (Lafarge Cement UK), Wiltshire, UK	Energy recovery	28,000 metric tons chipped tires/yr					Westbury Works Trowbridge Road Westbury Wiltshire UK BA13 4LX www.cement.bluecircle.co.uk		www.tyredisposal.co.uk (Select "Recycling Companies" and search by "Lafarge Cement.")
SATECH	Cushioned flooring technology			Tires		Cushioned gymnasium floors	Tom Vaux, creator		Touart, Adrienne P., "Life and Times of Clean Washington Center," *BioCycle*, July 1997, pp. 50–57.
Snowy River Enterprises, Longmont, Colo.		200,000 tires/yr					4450 Mulligan Dr. Longmont, CO 80504 Rustye Cole (907) 535-0535	New devulcanization technology by Levgum. Now exclusive rights for use in western hemisphere belong to Softstone (see below).	www.rubber.com/rubber/trade/index.html

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Softstone, Inc., Ardmore, Okla.							Kieth Boyd, President www.levgum.com	Rare case where steel is touted as a valuable product from tire recycling.	*Scrap Tire News,* July 2002, p. 17.
Spring Tire Recycling, Stoney Creek, Ontario, Canada							75 Muscot Drive Stoney Creek, ON L8J 1Y8 Canada Greg Cecato 905-692-9672		www.rubber.com/rubber/trade/index.html
Steel Recycling Institute, Pittsburgh, Pa.				Tires	Steel		Greg Crawford, vice president 800-937-1226	Crawford also notes that steel recovery is not easy. Consumer concern lies in the amount of rubber attached to the wire. Rubber-contaminated ferrous scrap causes changes in steel mill air emissions.	Powell, Jerry, "The Hottest Trends in Tire Recycling," *Resource Recycling*, December 1996, pp. 14–20.
STI-K Polymers America, Wash.	Devulcanization			Tires	Virgin rubber				Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp 18–27.

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Texas Industries, Hunter, Tex.	Burns tires for TDF	2,000,000 tires/yr		Tires		TDF for cement kilns			Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18–27.
The Tire Broker, Colorado Springs, Colo.							2660 Durango Dr. Colorado Springs, CO 80910 Dave Mehring (719) 499-6982	Steel from forklift tires being recycled.	www.rubber.com /rubber/trade/index .html
Thermal Systems, Niagara, N.Y.	Pyrolysis: heating of tires in an oxygen-starved environment to produce a fuel-like liquid, carbon char, and steel.			Tires	Fuel, carbon black				Powell, Jerry, "Signs of a Maturing Industry: The Recent Growth in Scrap Tire Recovery," *Resource Recycling*, March 1997, pp. 18–27.
Three-D Plastics, Inc., Burbank, Calif.							Three D Traffic Works 430 N Varney St Burbank, CA 91502 (877) 843-9757 www.trafficwks.com	Process tire retreader buffings.	*Scrap Tire News,* June 2002, p. 6.
Tire & Rubber Recyclers Inc, Pompano Beach, Fla.				tires			David W. Squier		Taylor, Brian, "On a Roll," *Recycling Today*, October 1999, pp. 28–36.
Tire Recyclers Inc., Richmond, Va.		100 tons of refined chips/day					710 N Hamilton St.,#210 Richmond, VA 23221-2035 Charlie White, President (804) 358-1303		www.rubber.com /rubber/trade/index .html *Scrap Tire News*, May 2002, p. 1.

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Tire Resource Systems, Sioux City, Iowa	Has a machine called TufCut that shears tires up to 6 ft in diameter, has Titan II that can handle tires up to 12 ft in diameter. The shear can also be used to cut the bead out of the tire after it is sectioned.			Tires	Large sections/ smaller shreds of OTR tires		Butch Hoffman		Phillips, Mark, "Land of the Giants," *Recycling Today*, March 1996, pp. 48–54, 84.
Tire Shredders Unlimited, Fenton, Mo.							170 Middleview Fenton, MO 63026 Bill Dennis (361) 992-5852		www.rubber.com/rubber/trade/index.html
Tire Solutions International, Seneca Falls, N.Y.							PO Box 275 Seneca Falls, NY 13148 James S. Tydings, Sr (315) 568-8809	Company is selling its tire-derived steel.	www.rubber.com/rubber/trade/index.html
Tirex Tire Recycling, Redding, Calif.	Shredding	100,000 tires/yr		Tires	Shreds		Keith Harrison, owner Tyler White		Phillips, Mark, "California Moves Aggressively in Managing Scrap Tire Problem," *Recycling Today*, October 1998, pp. 34–46.

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
TL & Associates, Fair Oaks, Calif.							8470 Bluff Lane Fair Oaks, CA 95628 Terry Leveille, President (916) 536-0451 terry@caltirereport.com	Facility can hold up to 10,500 tires. From each load, 35% are resold as waste tires, the rest are exported. Tires that cannot be sold are shredded and sent to local landfills. Future plans include crumb rubber processing.	www.caltirereport.com
Total Tire Recycling, Sacramento, Calif.	Shredding	3,000,000 tires/yr		Tires	Shreds		88588 Thys Court Sacramento, CA 95828 Michael Byrne (916) 568-3450	Reliable sources indicate company makes profitable use of tire fiber, but nothing yet published in the public domain.	Phillips, Mark, "California Moves Aggressively in Managing Scrap Tire Problem," *Recycling Today*, October 1998, pp. 34–46.
Tri-Rinse, St. Louis, Mo.	Shredding			Tires	Shreds	Landfill cover	Jim Waldron (314) 647-8388		Goodrich, Melissa, "Paving the Way," *Recycling Today*, April 2001, pp. 39–54.
University of Iowa, Iowa City, Iowa	Uses TDF			Tires		TDF as a supplemental fuel for coal-fired campus power plant.			"Iowa Continues to Search for Tire Markets," *BioCycle,* September 2001, p. 73.
Utah Tire Recyclers	Shredder			Tires	Crumb rubber			Shredded tires go to landfills for use as cover.	"Iowa Continues to Search for Tire Markets," *BioCycle,* September 2001, p. 73.

Facility Name/ Location	Description of Process/ Technology	Capacity	Operational Status (year)	Feedstock (tires, fiber, or steel)	Materials Recovered	Uses for Materials	Contact Info	Other Pertinent Info	Source/ Citation
Virginia Recycling, Providence Forge, Va.	Shredding	150,000 tires/yr		Tires	Shreds		PO Box 359 Providence Forge, VA 23140 Chris Kuhn (804) 966-5159	Company may know what its clients are doing with the steel that its device removes from tires.	Powell, Jerry, "The Hottest Trends in Tire Recycling," *Resource Recycling*, December 1996, pp. 14–20.
Voigts Mfg., Inc., Streator, Ill.						Steel bead wire	(815) 672-3602	Supplier of rubber/bead separator.	Scrap Tire News, April 1998 (ITRA Exhibition list)
Waste Recovery, Dallas, Tex.		2,000 tons/month		Tires	Steel			10%-20% used for retreading, 20% chipped for road and soil drainage civil engineering projects, 1%–2% for crumb rubber. Remainder goes out for TDF.	Powell, Jerry, "The Hottest Trends in Tire Recycling," *Resource Recycling*, December 1996, pp. 14–20.
Waste Recovery, Portland, Oreg.	State's only tire chipper	5,000,000 tires/yr		Tires	Chips, crumb rubber		Mark Hope, vice- president		Pedersen, Marialyce, "Scrap Tire Recycling: Turning the Corner of Success," *MSW Management*, January/February 1995, pp. 44–51.

Appendix C.
Contact Information From Literature Search

Name/Location	Contact Information
Allstate Tire Recycling Wolcott, Conn.	31 Nutmeg Valley Road Wolcott, CT 06716 Tel: 800-200-8000 E-mail: info@allstatetire.com
Amat Ltd., UK	Peter Skeels Managing & Engineering Director Tel: 44-1270 255 185 E-mail: peterskeels@amat-ltd.com www.amat-ltd.com
American Recycler Toledo, Ohio	PO Box 351748 Toledo, OH 43635-1748 Tel: 877-777-0737 E-mail: trish@americanrecycler.com
American Rubbertech Forest Hills, N.Y.	Frank Congemi 112-01 75th Avenue Forest Hills, NY 11375 Tel: 718-520-0401
American Tire Disposal, Inc. Colton, Calif.	1495 N Eighth Street Colton, CA 92324 Tel: 909-430-0880
American Tire Recyclers Woonsocket, R.I.	Mike 545 Front Street Woonsocket, RI 02895 Tel: 401-765-7977
American Waste Transport and Recycling Mount Laurel, N.J.	Bruce Levin 12-B The Ellipse Bldg., Suite 216 Mount Laurel, NJ 08054 Tel: 609-985-7300
American Pulverizer/Hustler Conveyer St. Louis, Mo.	5540 W Park Avenue St. Louis, MO 63110 Tel: 314-781-6100
Anderson Tire Recycling Anderson, S.C.	Doug Proctor 3520 Abbeville Hwy Anderson, SC 29624 Tel: 864-296-8405
Aquarius Inc. Torino, Italy	George Comerio Via Cavagnolo 40 Torino, Italy 10156 Tel: 39-11-2623694
Athenas Trading, S.A. São Paulo, Brazil	Reginaldo Gallo Al. Gabriel Monterio da Silva, 487 São Paulo, Brazil 01441-000 Tel: 5511 3085 8211
Atlantic Alliance Recycling Troy, N.C.	Steven Price, Vice President

Name/Location	Contact Information
Atlos Rubber, Inc. Los Angeles, Calif.	1522 Fishburn Avenue Los Angeles, CA 90063 Tel: 323-266-4570
Bay Area Tire Recycling L.L.C. San Leandro, Calif.	2615 Davis Street San Leandro, CA 9457 Tel: 510-562-4300
Bayshore Recycling Corp. Keasbey, N.J.	Al Ludwig 75 Crows Mill Road Keasbey, NJ 08832 Tel: 732-738-6000
Bedwell Park Limited Hearts, UK	Dave Peters Bedwell Avenue Essendon, Near Hatfield Hearts AL9 6AA UK Tel: 44-1707 273828
Bemco Recycling Allenwood, Penn.	Louis Belsito RD 1 Box 338 Allenwood, PA 17810 Tel: 7170538-2143
Blount Rubber Products, Trafford, Ala.	Van Mulvehill 928 Counyline Road Trafford, AL 35126 Tel: 205-647-3200
Boynton Brothers & Hallam (Ranskill) Ltd Ranskill, UK	John Boynton Access Road Ranskill, Near Retford Notts DN22 8LE UK
Bridgestone/Firestone, Inc. Ontario, Calif.	4000 E Mission Blvd. Ontario, CA 91761 Tel: 847-981-2200
British Rubber Manufacturers' Association Ltd. London, UK	6 Bath Place Rivington Street London EC2A 3JE UK Tel: 44-207-457-5040 E-mail: mail@brma.co.uk www.brma.co.uk
Buyer's Depot Eunice, La.	Charles Dugas 110 E Laurel Avenue Eunice, LA 70535 Tel: 318-546-6549
C.W. Owens Enterprises Southside, Ala.	Cecil Owens 3010 Mountain View Drive Southside, AL 35907 Tel: 256-442-1084
California Portland Cement Company Colton, Calif.	695 S Rancho Avenue Colton, CA 92324 Tel: 805-824-2401

Name/Location	Contact Information
Cb Tires, Inc. Grand Terrace, Calif.	21801 Barton Road Grand Terrace, CA 92313 Tel: 626-963-5084
Central Ohio Contractors, Inc. Grove City, Ohio	2879 Jackson Pike Grove City, OH 43123 Tel: 614-871-7479
Central Valley Tire Disposal Fresno, Calif.	1661 Grantland Fresno, CA 93706 Tel: 559-276-1208
Champlin Tire Recycling, Inc. Concordia, Kans.	PO Box 445 Concordia, KS 66901-0445 Tel: 800-295-3345 or 785-243-3345 E-mail: ctri@dustdevil.com www.driveusa.net/CTRcontact.htm
Coletta Recycling Corporation Far Rockaway, N.Y.	Michael Coletta 1629 Redfem Avenue Far Rockaway, NY 11691 Tel: 718-327-4740
Credential Tyre Recycling Ltd. Sheffield, UK	Nick Hiscox 18 Stevenson Road Attercliffe, Sheffield UK S9 3XG Tel: 44-114 242 1620 E-Mail: info@credtyres.co.uk www.credtyres.co.uk
Crm Company, LLC Compton, Calif.	15800 S Avalon Blvd. Compton, CA 90248 Tel: 310-538-2222
Crumb Rubber Industries Corcoran, Calif.	2940 W Whitley Avenue Corcoran, CA 93212 Tel: 559-992-2136
Crumbco International ; Inc. Sainte-Anne des Plaines; Quebec, Canada	Robin Fortin 140 des Enterprises Sainte-Anne des Plaines QC J0N 1H0 Canada Tel: 450-478-7227
CSB International Marketing Inc. Kissimmee, Fla.	Curtis Moore 800 Office Plaza Blvd, Unit 401D Kissimmee, FL 34744 Tel: 407-301-3911
D&N Tyre Recycling Selangor, Malaysia	Nicky The 39A, Jalan SS 19/6, Subang Jaya Petaling Jaya Selangor Malaysia 47500 Tel: 60-12-2380058

Name/Location	Contact Information
DME Tyres Staffs, UK	David Ebrey, Chairman Ring Road, Chase Terrace Burntwood, Staffs England WS7 8JQ Tel: 44 1543 677758
DME Tyres West Midlands, UK	Paul Buick Ring Road Chase Terrace, Walsall West Midlands UK WS7 8JQ Tel: 44-1543 677758
Emery Gas Corporation Salt Lake City, Utah	Benjamin Phillips 444 E 200 South Salt Lake City, UT 84111 Tel: 801-364-8283
EMTEK Industries Timmins, Ontario, Canada	Eileen Shewen 720 Laforest Road Timmins, ON P4N 7C3 Canada Tel: 705-264-4367
Encore Rubber Technologies Victoria, Australia	Annesley Osborne 30-56, Encore Avenue, Somerton Victoria, Australia 3062 Tel: 61 03 9305 2585
Entech White Pigeon, Mich.	Tel: 574-533-4325 E-Mail: craig@4entech.com
Equi-tread Black Creek, British Columbia, Canada	Pamela Jorgensen 2347 Hamm Road Black Creek, BC V9J 1B4 Canada Tel: 888-547-3399
European Tyre Recycling Association (ETRA) Paris, France	Valerie Shulman 7, rue Leroux Paris France 75116 Tel: 33.1.45.00.37.77
Felmex International Tucson, Ariz.	Steven Rice 321 S Kino Parkway Tucson, AZ 85719 Tel: 520-770-1519
First American Scientific Corporation Vancouver British Columbia, Canada	Ian Nagy 303-409 Granville Street Vancouver, BC V6C-1T2 Canada Tel: 604-681-8656
Fitzsimmons Waste Tire Pile, Fitzsimmons #2 Waste Tire Site Rosamond, Calif.	9171 W Rosamond Blvd. Rosamond, CA 93560 Tel: 805-256-2616

Name/Location	Contact Information
Florida Tire Recycling St. Lucie, Fla.	Susan Wilson, President
G.C.P. Elastomerics Inc. Kitchener, Ontario, Canada	Gary Mottershead Tel: 519-893-8207 Anton Gust Tel: 773-404-2005
Garb-Oil & Power Corporation Salt Lake City, Utah	John Brewer Tel: 801-832-9865
Gebrauchtrefenhandel Philpott Bramsche, Germany	Francis Philpott Uhlenbrock 10 Neuenkirchen (Bramsche) Germany 49586 Tel: 49-5465209116
Global Recycling Network Guelph, Ontario, Canada	PO Box 24071 Guelph, ON N1E 6V8 Canada Tel: 519-658-9580
Global Scrap Processors & Traders India	Sandeep Mehta 301, panchkalyan, kala nala Bhavnagar gujarat, India 364001 Tel: 91-9824077777
GRR Inc. St. Thomas, Ontario, Canada	Patrick Blanshard 75 Edgeware Road S St. Thomas, ON N5P-2H7 Canada Tel: 519-637-8205
Henderson Equipment & Commodities Dunedin, Fla.	Chris Hendersen 1015 Forest Court Dunedin, FL 34698 Tel: 727-492-6841
Huffman Rubber, Inc. Homer, Mich.	Alan Huffman 7510 25½ Mile Road Homer, MI 49245 Tel: 517-568-3353
Huron Recovery Buffalo, N.Y.	Michael Honer 300 Greene Street Buffalo, NY 14206 Tel: 716-894-0209
Huronco Huron Park, Ontario, Canada	Bill Strong Box 542 Huron Park, ON N0M 1Y0 Canada Tel: 519-228-6634

Name/Location	Contact Information
Industrial Power Technology Santa Rosa, Calif.	2227 Capricorn Way, Suite 101 Santa Rosa, CA 95407 Tel: 707-578-6144 www.ipower-tech.com/wadham.html
Institute of Scrap Recycling Industries, Inc. Washington, D.C.	Tom Tyler 1325 G Street NW, Suite 1000 Washington, DC 20005 Tel: 202-662-8516 E-Mail: tomtyler@isri.org
Integrated Tire Bayonne, N.J.	Ron Piggot 2 E 2nd Street Bayonne, NJ 07002 Tel: 716-847-8473
Integrated Tire Buffalo N.Y.	Richard Johnson 333 Ganson Street Buffalo, NY 14203 Tel: 716-847-8473
Inter-East Tire, Inc. (Lakin Tire) Westhaven, Conn.	David Greenstein 240 Frontage Road Westhaven, CT 06516 Tel: 203-932-5801 x308
J&F Tire, Inc. Washington, Penn.	Frank Andy 331 Old Hickory Ridge Road Washington, PA 15301 Tel: 724-225-4888
Jackson Valley Energy Partners L.P. Ione, Calif.	4655 Coal Mine Road Ione, CA 95640 Tel: 209-274-2407
JANRT Tire Recycling Equipment, L.L.C. Muncie, Ind.	Tel: 765-282-3014 www.scraptirepower.com/index.html
Jayne's Tire Recycling Elizabeth, N.J.	Douglas Jayne PO Box 23 Elizabeth, NJ 07207-0023 Tel: 732-447-6243
Kingpin Remoulds Ltd. Shropshire, UK	Rikki Proudlove Unit C8, Wem Industrial Estate Soulton Road Wem Shropshire UK SY4 5SD Tel: 44-1939 232156
Konings Rubber Technology B.V. Swalmen, The Netherlands	Tel: 31-475-500100
L.B.'s Tire Recycling Warren, Mich.	Vince Macri 22349-A Grosebeck Hwy Warren, MI 48089 Tel: 810-771-8350

Name/Location	Contact Information
Lakin General, Inc. Chicago, Ill.	Ken Lakin 2044 N Dominick Street Chicago, IL 60614 Tel: 773-871-6360
Lakin Tire West, Inc. Santa Fe Springs, Calif.	14930 Marquardt Avenue Santa Fe Springs, CA 90670 Tel: 562-802-2752
Lakin Tire West Haven, Conn.	15305 Spring Avenue Santa Fe Springs, CA 90670 800-488-2752 240 Frontage Road West Haven, CT 06516 Tel: 800-368-8473 E-Mail: RandyRoth@lanintire.com
Lehigh Southwest Cement Co. Redding, Calif.	15390 Wonderland Blvd. Redding, CA 96003 Tel: 530-275-1581
L-Tek Associates Utica, N.Y.	Thomas Colucci 124 Kensington Drive Utica, NY 13501 Tel: 315-601-1073
Marion Recycling Marion, Ill.	Rhonda McBride 1202 E Main Marion, IL 62959 Tel: 618-997-9448
Maschinenbau und Umwelttechnik GmbH Rostock, Germany	W. Begler Joachim Jungius-Str. 9 18059 Rostock Germany Tel: 49-381–4059354 E-Mail: MBU-GmbH@t-online.de
Material Recovery of North America Socorro, N. Mex.	Tel: 505-835-9333
Mazco Tire Recycling Inc. Commack, N.Y.	Paul Mazzola 158 Burr Road Commack, NY 11725 Tel: 631-462-1960
Mecklenburg County Metal & Tire Recovery Charlotte, N.C.	5740 Rozzelles Ferry Road Charlotte, NC Tel: 704-392-1063
MeWa Recycling Maschinen und Anlagenbau GmbH Baden-Wurttemberg, Germany	Karsten Mennerich Gultlinger Strasse 3 Gechingen Baden-Wurttemberg Germany D-75391 Tel: 49-0756-925-0
Mitsubishi Cement Corporation Lucerne Valley, Calif.	5808 State Hwy 18 Lucerne Valley, CA 92415-0160 Tel: 619-248-7373

Name/Location	Contact Information
Modesto Energy Limited Partnership, Westley, Calif.	4549 Ingram Creek Road Westley, CA 95387 Tel: 510-244-1100
Mt. View Recyclers Tucumcari, N. Mex.	Jack Malone PO Box 1476 Tucumcari, NM 88401 Tel: 505-461-2133
Nathaniel Energy Corporation Hutchins, Tex.	
Nor-Cal Recyclers Oroville, Calif.	1855 Kusel Road Oroville, CA 95966 Tel: 530-532-0262
North American Recycled Rubber Association Whitby, Ontario, Canada	1621 McEwen Drive #24 Whitby, ON L1N 9A5 Canada Tel: 905-433-7669
Northeast Recycling Council Brattleboro, Ver.	139 Main Street, Suite 401 Brattleboro, VT 05301 Tel: 802-254-3636 E-Mail: info@nerc.org www.nerc.org
Pacific Rubber Supply, LLC Delta, British Columbia, Canada	Michael Harrington Tel: 909-244-7169
Paramount Rubber Recycling Concord, Ontario, Canada	Scott Hutchinson 582 Bowes Road Concord, ON L4K 1K2 Canada Tel: 905-738-0022
Parker Tire Disposal Hudson, Ohio	Richard Parker 5608 Akron-Cleveland Road Hudson, OH 44236 Tel: 330-656-3150
Rapra Technology Ltd. Shropshire, UK	Shawbury, Shrewsbury Shropshire SY4 4NR UK Tel: 44-1939 250383
The Recycler's Exchange (RecycleNet Corporation) Richfield Springs, N.Y.	PO Box 1910 Richfield Springs, NY 13439 Tel: 519-767-2913 www.recycle.net/exchange/
Re-Tire Disposal Harrow, Ontario, Canada	Mike Vagi RR 1 Harrow, ON N0R-1G0 Canada Tel: 519-738-3498

Name/Location	Contact Information
Rio Bravo Jasmin Bakersfield, Calif.	11258 Porterville Highway Bakersfield, CA 93380 Tel: 805-393-2278
Rio Bravo Pozo Bakersfield, Calif.	16608 Porterville Highway Bakersfield, CA 93380 Tel: 805-393-2278
Rouse Rubber Industries Vicksburg, Miss.	PO Box 820369 Vicksburg, MS 39182 Tel: 601-636-7141
The Rubber Group King of Prussia, Penn.	Mike Hovsepian 451 Yerkes Road King of Prussia, PA 19406 Tel: 610-878-9200
Rubber Manufacturers Association Washington, D.C.	Michael Blumenthal 1400 K Street NW, Suite 900 Washington, DC 20005 Tel: 202-682-4800 E-Mail: Michael@rma.org www.rma.org
Rubber Recycling, Inc. Arendtsville, Penn.	Dave Volland PO Box 190 Arendtsville, PA 17303 Tel: 717-677-8167
S&M Prompt Rubbish Removal, Tire Division Freeport, N.Y.	Salvatore F. Mancuso 228 Miller Avenue Freeport, NY 11520 Tel: 516-223-2010
SafeLandings, Inc. Kingston, N.Y.	Dick Varnum 52 Third Avenue Kingston, NY 12401 Tel: 914-338-0210
Sanhuan Environmental Protection Equipment Co., Ltd. Dalian Laioning, China	Young Lee No. 481, Xinan Road Shahekou District Dalian Liaoning, China 116021 Tel: 56-86411 4637781
Scrap Tire Management Council Washington, D.C.	Michael Blumenthal 1400 K Street NW, Suite 900 Washington, DC 20005-2403 Tel: 202-682-4800
Scrap Tire Recycling Inc. Pasadena, Tex.	Virginia Barnes PO Box 3251 Pasadena, TX 77347 Tel: 713-481-2657

Name/Location	Contact Information
Shred-Tech Cambridge, Ontario, Canada	295 Pinebush Road Cambridge, ON N1T 1B2 Canada Tel: 519-621-3560 E-Mail: shred@shred-tech.com www.shred-tech.com
SolidBoss/AirBoss Tires Lilburn, Ga.	Robert Gilkenson 930 Cedar Bluff Trail Lilburn, GA 30047 Tel: 770-923-9937
Sorbilite, Inc. Virginia Beach, Va.	5721 Bayside Road Virginia Beach, VA 23455 Tel: 757-464-3564
Steel Recycling Institute Pittsburgh, Pa.	Greg Crawford, VP Operations 680 Andersen Drive Pittsburgh, PA 15220 Tel: 800-876-7274 E-Mail: Craw67ford@aol.com
Sukomi Waste Management Beirut, Lebanon	Mohammed Hamzeh Karantina, Sable Bldg, 1st Floor Beirut, Lebanon 000 Tel: 961-1 562124/5/6/7/8/9
T.C.A. Tire Recycling Niagara Falls, Ontario, Canada	Tom Sorgenfrei RR #3 Niagara Falls, ON L2G 5V6 Canada Tel: 905-374-8397
TAMCO Rancho Cucamonga, Calif.	Leonard Robinson, Environmental Safety Manager Rancho Cucamonga CA Tel: 909-899-0631 E-Mail: RobinsonL@tamcosteel.com
Tega International New York, N.Y.	Masimba Musoni 666 W End Avenue New York, NY 10025
The University of Sheffield Sheffield, UK	Dr. Kypros Pilakoutas Reader, Dept of Civil and Structural Engineering Manager of the Centre for Cement and Concrete Sir Frederick Mappin Building Mappin Street Sheffield S1 3JD UK Tel: 44-114 222 5065 E-mail: K.Pilakoutas@sheffield.ac.uk

Name/Location	Contact Information
Tire Recycling Atlantic Canada Corporation (TRACC) Minto, New Brunswick, Canada	Jill Glenn 149 Industrial Park Road Minto, NB E4B 3A6 Canada Tel: 506-327-4355
Tire Recycling Consultants Ft. Lauderdale, Fla.	PO Box 290034 Ft. Lauderdale, FL 33329 Tel: 800-557-5692 E-mail: admin@recyclingtires.com www.recyclingtires.com
Tire Recycling Management Association of Alberta Edmonton, Alberta, Canada	Terry Robinson PO Box 189 Edmonton, AB T5J 2J1 Canada Tel: 780-990-1111, 888-999-8762 E-mail: trma@trma.com
Tire Resource Systems, Inc., Sioux City, Iowa	Tel: 712-255-5701
Tire Shredders Unlimited Fenton, Mo.	Bill Dennis 170 Middleview Fenton, MO 63026 Tel: 361-992-5852
Trinity Tire and Wheel Easton, Pa.	Larry More 4304 Winfield Terrace Easton, PA 18045 Tel: 610-250-0557
UK Tyre Processors Lancashire, UK	Unit 11, Whitelands Road Ashton Under Lyne Lancashire UK OL6 6UG Tel: 44-1636 3432316
Unified Tire Recovery, Inc. Cleveland. Ohio	Steven Barber 760 Beta Drive, Suite F Cleveland, OH 44143 Tel: 800-799-8473
Unisphere Waste Conversion Ltd. Toronto, Ontario, Canada	Brendan Wypich 84 Avenue Road Toronto, ON M5R 2H2 Canada
United States Council for Automotive Research	www.uscar.org
Used Tyre Working Group UK	www.tyredisposal.co.uk
Want Not Recycling Inc, Round Lake Beach, Ill.	William Carner 1312 Poplar Round Lake Beach, IL 60073 Tel: 847-546-0685

Name/Location	Contact Information
Waste Management and Research Northampton, UK	Belinda Bowers International Solid Waste Association IWM Business Services 9 Saxon Court, St. Peter's Gardens Northampton NN1 1SX UK Tel: 44-1 604 620 426 E-Mail: belinda.bowers@iwm.co.uk www.iswa.org
Waste Tire Products Research & Development Orland, Calif.	3820 Highway 99 West Orland, CA 95963 Tel: 916-699-0660
Waste Tyre Solutions, Ltd. Newton Aycliffe, UK	Bede House, St. Cuthbert's Way Aycliffe Industrial Park Newton Aycliffe DL5 6DX UK Tel : 01325 379020 E Mail: wts@wastesolution.co.uk www.wastetyres.com/
Watertown Recyclers Watertown, Wis.	Thomas Springer 7932 Provimi Road W Watertown, WI 53098 Tel: 920-261-7866
Web Enterprises Dayton, Va.	Warren Beery 7517 Rushville Road Dayton, VA 22821 Tel: 540-879-2350
Wendt International Corporation Tonawanda, N.Y.	Tel: 716-874-3344
Western Tire Shredders Inc. Calgary, Alberta, Canada	Troy Cole 3400, 425-1 Street SW Calgary, AB T2P 3L8 Canada Tel: 403-216-3370
World Rubber Northants, UK	Upper Higham Lane Rushden Northants UK NN10 0SU

Appendix D.
Sample Survey Forms

Tire Processors and Recyclers -- Survey Form

Please correct any errors in the address below.

Name of person completing form:

____

Telephone number:

____

Please write in information, or check boxes as instructed.

Name of facility	
Year facility first operated	

Operational scale/status (check appropriate box)	**Commercial**	**Startup**	**Demonstration**	**Research**
Fiber recovery				
Steel bead recovery				
Steel belt recovery				

Number of tires processed per 8 hrs	**Passenger**	**Truck**	**Passenger/Truck**

Disposition of fiber and steel byproduct (check appropriate box)	**Recycled**	**Disposed**
Fiber		
Steel bead		
Steel belt		

Description of technology used to recover byproducts	
Fiber	
Steel bead	
Steel belt	

Production quantities (tons) per 8 hrs	
Fiber fraction	
Steel bead fraction	
Steel belt fraction	

Composition of Recovered Material Fractions	**Nominal Particle Size**		**Composition[1]**						**Loose Density (lb/ft^3)[1]**
			Steel		**Fiber**		**Rubber**		
Fraction	**Value**	**Units**	**wt %**	**vol %**	**wt %**	**vol %**	**wt %**	**vol %**	
Steel									
Fiber									

[1] In table, indicate measured (*M*) or estimated (E).

CalRecovery, Inc. · 2454 Stanwell Drive · Concord, CA 94520
Phone: **866-848-3337 (toll-free in US)**, 925-356-3700 · FAX: 925-356-7956 · Email: mail@calrecovery.com

Note: *Please complete reverse side of this questionnaire* →

Describe markets/uses	
Fiber	
Steel	

	Fiber		Steel Bead		Steel Belt	
	$/ton	Mileage	$/ton	Mileage	$/ton	Mileage
If recycled, byproduct market price (FOB user) and mileage to user						
If disposed, cost of disposal and mileage to user						

Market demand trends	Good	Fair	Poor	No Market
Fiber				
Steel bead				
Steel belt				

Tire supply trend (check appropriate box)	☐ Increasing	☐ Steady	☐ Decreasing

Barriers to recycling fiber or steel	Fiber		Steel Bead		Steel Belt	
	Yes	No	Yes	No	Yes	No
Market price too low						
Distance to market too great						
Inadequate product specifications						
Product purity required by market is too high						
Uneconomical to add required additional processing equipment						
Technology (processing) improvements required						
Lack of demand/end uses						
Other (describe)						

Suggestions to improve marketability	Fiber		Steel Bead		Steel Belt	
	Yes	No	Yes	No	Yes	No
Simulate development of new products						
Promote processing technology improvements						
Other (describe)						

One of the difficulties of recycling metal/fabric recovered from the processing of used tires is the level of contamination of those materials with adhering rubber or with other forms of rubber contamination. What new technologies or techniques are you aware of that might have a bearing on this problem, or that your company is considering?

Markets of Tire By-Products -- Survey Form

Please correct any errors in the address below.

Name of person completing form:

____

Telephone number:

____

This market survey on steel and fiber derived from processed tires seeks to gather data from traders, resellers, processors, and consumers, as well information on as any resultant materials or fuel derived from processed tires or their byproducts.

Please answer questions as applicable to your company situation, as well as from an industry perspective (e.g., fiber or metal recyclers, resellers, tire-derived fuels (TDF) users, other fuel purchasers, formulators, fiber and steel producers, iron foundries, and providers of end product applications based on steel and fiber from waste tires or waste tires themselves that incorporate steel and fiber). This survey form is lengthy due to the breadth of actual and potential markets and uses. However, only limited portions of the survey may apply to your company. The following table is meant to facilitate your use of the form and to direct you to those portions of the survey that are likely applicable to a specific type of user.

Material	**Section(s)**
Steel	1-6, 7A, 8A, 9, 11A, 12A, 13, 14
Fiber	1-6, 7B, 8B, 9, 10, 11B, 12B, 13, 14
Fuel or Pyrolysis	1-6, 9, 13, 15

---

1. Personal experience either in recovery of, or consumption of, tire bead wire, tire belt wire, other tire body wire; fibers recovered whole or after tire recycling by chopping, shredding, or making tire-derived fuel (TDF); or post-combustion forms of TDF? Yes ☐ No ☐

Company experience? Yes ☐ No ☐

Please recommend contact information for any industry steel or fiber experts that can contribute to the goal of finding commercial outlets for tire-derived steel and fiber. ______________________________

____

2. Do you have operating facilities that process or use tire-derived steel or fiber?

Item	**Locations**	**Number of Plants**	
		Steel	**Fiber**
1	In California		
2	In states adjacent to California		
3	In the US (other than in Items 1 or 2)		
4	International		

CalRecovery, Inc. • 2454 Stanwell Drive • Concord, CA 94520
Phone: **866-848-3337 (toll-free in US)**, 925-356-3700 • FAX: 925-356-7956 • Email: mail@calrecovery.com

3. What is the source of your steel and fiber by recycling and recovery operations?

Operation	**Yes**	**No**
Chopping		
Shredding		
TDF (tire-derived fuel)		
Grind – ambient		
Grind – cryogenic		
Grind - wet		
Chemically recovered		
Pyrolysis		

4. How are steel or fiber recycled from tires acquired by your operations?

Method	**Yes**	**No**
Part of your recycling operations		
Directly from tire recycler		
Distributor, importer, exporter, reseller		
Scrap dealer		
Formulator/converter		
Company that primarily handles tire wire, bead wire, or tire fabric		
Company that manufactures or recycles fibers or steel		
Other (please provide)		

5. Does your company have a set of standard specifications for any physical forms of tire-recycled steel or fiber sold or used by your operation? Yes ☐ No ☐

a. Please attach brochure or specifications for the steel and fibers.

b. Are these specifications also industry-standard specifications? Yes ☐ No ☐

c. If there are no industry-standard (i.e., consensus) specifications at this time, are you aware of any organizations that are or may be developing specifications at this time? Yes ☐ No ☐
Please provide name and contact information: ________________________________

d. If you do not have a formal set of specifications, could you please indicate the important parameters when you are considering the feasibility of handling or using a steel or fiber material in your process for the first time?

____

6. What action or channel describes the communication methods available to you for making known your buying requirements or your selling availability for steel or fiber from recycled tires? Circle letter of all that apply among Items a to n and circle the whole answer for the most important.

a. Word of mouth	h. Third-party Internet exchange, trading platform, or offer to buy or sell listing site
b. Established contract	i. Company website
c. Long-term relationship	j. Tire recycler
d. Reseller, distributor, or trader communications	k. Reprocessor of steel or fiber
e. Industry publication	l. Scrap dealer
f. Consultant	m. Competitor
g. Government entity	n. Other

2

7. In your opinion, what is the state of development of tire-derived steel and fiber for the industry and for your company? Please check the appropriate boxes.

	State of Development								
	Commercial		Startup		Demonstration		Research		Limited or No Potential
	Industry	Company	Industry	Company	Industry	Company	Industry	Company	
7A. Tire-derived Steel									
Reprocessing or reuse of tire bead wire									
Reprocessing or reuse of tire belt wire									
Reprocessing or reuse of other tire body wire									
Steel production scrap material for electric arc furnace process									
Steel production scrap material for basic oxygen or blast furnace processes									
Other steel production process raw material									
Iron or steel from tire-derived fuel (TDF) or direct tire or tire component combustion									
Cement kiln energy or process material and resultant iron or steel recovery									
Incorporated in end product application(s) as part of the use of tire rubber recycling									
Other steel (describe)									
7B. Tire-derived Fiber									
Reprocessing to basic polymer resins									
Reuse as filler application(s)									
Reuse insulation application (s)									
Reuse in carpet blends									
Reuse in carpet underlays									

	State of Development								
	Commercial		Startup		Demonstration		Research		Limited or No Potential
	Industry	Company	Industry	Company	Industry	Company	Industry	Company	
Used in reinforced plastics									
Cement kiln energy and process material feedstock									
Incorporated in end product application(s) as part of the use of tire rubber recycling									
Other fiber (describe)									

8. What barriers, if any, confront your company with regard to using materials with recycled content?

Potential Recycling Barrier Issues	Is this an issue, in your opinion?			
	8A. Steel		8B. Fiber	
	Yes	No	Yes	No
1. Consistent, adequate quality of recycled material				
2. Contamination or compatibility issues				
3. Delivered price of recycled materials vs. that of alternatives				
4. Inadequate supply levels				
5. Added investment or operating costs needed				
6. Delays from acceptance by buyers, by customers of buyers, or from advocacy groups seeking limited recycled tire materials				
7. Development time for application or process				
8. Restricted processing or storage space				
9. Patent or other legal issues				
10. Environmental, health, safety, permits, or other government regulations				
11. Public policy impediments				
12. Other				
Recommendations for overcoming any of the above issues[1]				

[1] Please note by number (e.g., using 4 for Inadequate Supply Levels, etc.) and specify any recommendations for overcoming.

9. What problems are caused in your process or with regard to end product quality and operational considerations from:

a. Natural and synthetic rubber attached to steel or fiber? Please describe:____________________

b. The attached rubber having over 1% sulfur content? Please describe:____________________

c. Brass or bronze coatings (copper and zinc) used on steel tire bead, belt wire, and other body wire? Please describe:____________________

d. Tire-derived fiber, typically a fluff, consisting of a mixture of fiber types (primarily polyester and nylon)? Please describe:____________________

10. For your operations or your customer's applications, is it necessary for one or more fiber types (e.g., polyester) to be separated? Yes ☐ No ☐

a. Does your operation have an ability to separate fiber types (e.g., polyester) for reuse? Yes ☐ No ☐

b. Does anyone in the industry practice separation or segregation of fiber types? Yes ☐ No ☐

c. Suggested contacts, if any:____________________

11. What are your annual feedstock requirements and percentage (%) of steel and/or fiber content from recycled tire-derived material?

Type of Material	Annual Requirement (tons)		Percentage of Tire-derived Recycled Material (%)
	Virgin	Recycled	
11A. Steel, All Uses			
Steel bead			
Steel belt			
Other steel body			
11B. Fiber			
Polyester			
Nylon			
Aramid			
Rayon			
Other tire fiber			
Mixed fiber			

12. For your company, what has been the percentage (%) of growth for tire-derived steel or fiber applications over the past 5 years, and what do you anticipate for the next 5 and 10 years?

		Percent of Growth			Describe Steel or Fiber Type
		Past	Next		
		5 years	5 years	10 years	
12A. Steel	In California				
	In the US (other than CA)				
	International				
12B. Fiber	In California				
	In the US (other than CA)				
	International				

5

13. What unit price are you willing to pay (or would you charge) to procure tire-derived feedstocks?

Product Category	Price, FOB Market ($/ton)	Applicable Steel or Fiber Grade
Home scrap[2] bead wire		
Home scrap[2] belt wire		
Other body wire		
Scrap tire steel (containerized, shredded)		
Scrap tire steel (wire or belt bundles)		
Scrap tire steel (forklift tires)		
Recovered steel from TDF or pyrolysis applications		
Home scrap tire polyester fabric/fiber[2]		
Home scrap tire nylon fabric/fiber[2]		
Scrap tire mixed fabric/fiber (fluff)		
Scrap tire mixed fabric/fiber baled or compacted (fluff)		
Scrap tire polyester fabric/fiber baled or compacted (fluff)		
Scrap tire nylon fabric/fiber baled or compacted (fluff)		
Tire/steel or fiber composite[3] (product:)		
(product:)		

14. What industry sources post, publish, or suggest applicable market prices? Please list by steel or fiber type. Steel______________________________

Fiber______________________________

15. For tire-derived fuel (TDF) users (including users of tires for pyrolysis)[4]:

Average annual input mmBtu requirement	
% Heat input met by primary non-recycled fuel (e.g., natural gas or coal)	
% Heat input met by recycled fuel (wood waste, tires, etc.)	
Type of TDF used (enter TW for whole tire, TC for tire chips, or F for fiber)	
% input heat requirement met by TDF	
Average firing rate of TDF (tons/year)	
Average production of post-combustion TDF steel (tons/yr)	
Maximum firing rate of TDF (tons/year)	
List of competitive fuels to TDF	
Average cost of alternative fuels ($/mmBtu)	
Revenue (or cost) of recycling (or disposing) of post-combustion TDF steel	
List any limitations of using TDF	

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[2] i.e., waste or floor scrap from bead or belt wire manufacturers or tire fabric manufacturers.

[3] For example, tire chip aggregate, or playground base.

[4] Include any tire and TDF materials used as raw materials.

Producers of Tire Products -- Survey Form

Please correct any errors in the address below.

Name of person completing form:

____

Telephone number:

____

This survey is to gather data from tire manufacturers and from producers of steel, fibers, and the steel and fiber components of tires (e.g., tire cord, bead, and belt wire.) Please especially answer questions that apply to your industry (e.g., fabric questions for fabric producers). To facilitate ease of responding, we have organized the survey into three sections: Section I is for tire manufacturers only and Sections II and III are for tire, fiber, and steel belt manufacturers.

SECTION I: For Completion by Tire Manufacturers Only

Please comment regarding typical compositions for your company's tires as compared to the following table of generalized industry data. We would also be grateful in receiving any relevant, non-proprietary information or company brochures on tire specifications, including steel and fiber, in connection with the return of this questionnaire.

Typical Compositions (Weight Percent) and Gross Weights (lbs) of Tires

	Passenger						Truck					
Ply	Radial				Bias		Radial				Bias	
	All Steel		All Fiber				All Steel		All Fiber			
Material	*RMA*[1]	[2]	*RMA*[1]	[2]	*RMA*[1]	[2]	*RMA*[1]	[2]	*RMA*[1]	[2]	*RMA*[1]	[2]
Steel	10-15%		3-4%		3-4%		14-16%		3-4%		3-4%	
Bead wire	3-4%		--		3-4%		3-4%		3-4%		3-4%	
Other wire[3]	7-11%		--		--		11-12%		--		--	
Fiber[3]	--		4-7%		7%		< 0.5%		4-9%		9%	
Belt (estimate)[3]												
Body (estimate)												
Average Weight	***RMA***[1]			***Respondent's Value***			***RMA***[1]			***Respondent's Value***		
New tire	25						120					
Used tire	20						100					

Some references state that due to tread wear during vehicle use, used tires typically have 1% higher levels of steel and fiber than those shown above (e.g., in the case of all-steel belted radial tires, the steel content would be 16% to 21%, as opposed to 10% to 15). ***Do you have any comments if this estimate is accurate?***

Comments regarding changes in composition and unit weight of tires in the future as a result of likely

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1 Source: Based on Rubber Manufacturers Association, 2002.

2 Respondent's value.

3 Total tire fabric: if steel cord, its percentage of total; if fiber cord, its percentage.

CalRecovery, Inc. - 2454 Stanwell Drive - Concord, CA 94520
Phone: **866-848-3337 (toll-free in US)**, 925-356-3700 - FAX: 925-356-7956 - Email: mail@calrecovery.com

technological innovations:

Based on technology, economic and other drivers, or restraints over the next five to ten years, what total percentage increase or decrease do you see in the following?

	Total Percent Increase (or Decrease[4])[5]		Comments
	5 years	10 years	
Average tire life			
Average tire weight			
Passenger tire retreading units			
Truck tire retreading units			
Average belt fiber content			
Average body fiber content			
Average steel bead			
Average steel belt content			
Average other steel body content			
Other factors affecting use of fiber and steel in tires (specify)			

What are your estimated unit shipments of non-OEM tires in California in 2001?

SECTION II: Tire Fiber

	Your Company Supplies (*to be completed by PRODUCERS*)		Your Company Uses (*to be completed by TIRE MANUFACTURERS*)			
				Passenger	Truck	Other
Tire Fiber	Check all fibers that apply	Rank by volume (1 for largest, etc.)	Check all fibers that apply	Rank by volume (1 for largest, etc.)		
1. Polyester terephthlate (PET)						
2. Polyethylene naphthalate (PEN)						
3. Aromatic polyamide						
4. Other polyester						
5. Nylon						
6. Rayon						
7. Other tire fiber						
8. (Please specify)						
Developments/Trends[5]						

[4] Indicate decreases in parentheses "( )."

[5] Considering developments and trends, how do you anticipate these components to change over the next 5 and 10 years (e.g., type of materials, weight)?

SECTION II: Tire Steel

We would also be grateful in receiving any relevant, non-proprietary information or company brochures on tire specifications, including steel and fiber, in connection with the return of this questionnaire.

		Tire Model	
Type of Tire Wire		Typical passenger tire	Typical truck tire
Tire size (complete the data for a "typical" (please circle) tire of your production, or specify a popular tire size (please indicate)		Typical Tire Size	Typical Tire Size
Bead wire	Grade of steel, e.g., AISI Grade		
	Coating (Blank means no coating)		
2001 US domestic shipments (tons)			
Percentage increase or decrease in next 5 years (circle which)		%	%
Steel belt wire	Grade of steel, e.g., AISI Grade		
	Coating (Blank means no coating)		
2001 US domestic shipments (tons)			
Percentage increase or decrease in next 5 years (circle which)		%	%
Other steel body wire	Grade of steel, e.g., AISI Grade		
	Coating (Blank means no coating)		
2001 US domestic shipments (tons)			
Percentage increase or decrease in next 5 years (circle which)		%	%
Developments/Trends[f]			

SECTION III: Recycling Issues (complete as applicable to your industry)

What is the developmental status of tire-derived steel and fiber? Please check the appropriate box.

	Status of Development				
	Commercial	Startup	Demonstration	Research	Limited or No Potential
Potential for Reuse of Recycled Steel					
• Reprocessing or reuse of tire bead wire					
• Reprocessing or reuse of tire belt wire					
• As steel mill raw material					
• Scrap metal applications such as rebar					
• Iron or steel from tire-derived					

[f] Please note by number (e.g., using 5 for nylon, etc.) any developments and/or trends for each fiber. Considering developments and trends, how do you anticipate these components to change over the next 5 years (e.g., type of materials, weight)?

	Status of Development				
	Commercial	Startup	Demonstration	Research	Limited or No Potential
fuel					
• Incorporated in end product application(s) as part of the use of tire rubber recycling					
• Other steel use (specify)					
Potential for Reuse of Recycled Fiber					
• Cement kiln energy and process material feedstock					
• Reprocessing to basic polymer resins					
• Reuse as filler application (s)					
• Reuse insulation application (s)					
• Reuse in carpet blends					
• Reuse in carpet underlays					
• Used in reinforced plastics					
• Incorporated in end product application(s) as part of the use of tire rubber recycling					
• Other fiber use (specify)					
If the status of development is poor, describe reasons (e.g., coating of belt wire or particular fiber type is detrimental to process)					

Has your company established or specified a recycled content for tires or their components as a corporate goal? Yes ☐ No ☐

	Rubber	Steel			Fiber	
		Bead	Belt	Other Body	Belt	Body
Please specify percentage or range of percentages	%	%	%	%	%	%
Year goal applies						

If your company has not established goals, would you support or consider supporting a minimum recycled content for the product/material? Would Support ☐ Would Consider Supporting ☐

As opposed to any recycled content goals specified above, what percentage (of total existing use in new tires) of recycled content, if any, have you actually achieved in practice as a consequence of reusing or reprocessing steel, fiber, or rubber materials from used tires?

Timeframe	Rubber	Steel			Fiber	
		Bead	Belt	Other Body	Belt	Body
Reuse in Tires						
Current	%	%	%	%	%	%
5-year estimate	%	%	%	%	%	%

Other Reuse (specify)[7]						
Current	%	%	%	%	%	%
Likelihood in 5 years	%	%	%	%	%	%

What barriers, if any, confront your company with regard to using materials with recycled content?

Potential Recycling Barrier Issues	Is this an issue, in your opinion?			
	Steel		Fiber	
	Yes	No	Yes	No
1. Consistent, adequate quality of recycled material				
2. Contamination or compatibility issues				
3. Delivered price of recycled materials vs. that of alternatives				
4. Inadequate supply levels				
5. Added investment or operating costs needed				
6. Delays from acceptance by buyers, by customers of buyers, or from advocacy groups seeking limited recycled tire materials				
7. Development time for application or process				
8. Restricted processing or storage space				
9. Patent or other legal issues				
10. Environmental, health, safety, permits, or other government regulations				
11. Other				
Recommendations for overcoming any of the above issues[8]				

One of the difficulties of recycling metal/fabric recovered from the processing of used tires is the level of contamination of those materials with adhering rubber. What new tire technologies or construction techniques are you aware of that might have a bearing on this problem, or that your company is considering, or the tire manufacturing industry is considering?

____

____

____

____

[7] For example, rubber used as construction aggregate.

[8] Please note by number (e.g., using 4 for Inadequate Supply Levels, etc.) and specify any recommendations for overcoming.

Appendix E.
Specifications for Steel From Scrap Tires

These specifications are from the "Steel From Scrap Tires" section of the "ISRI Scrap Specifications Circular 2003: Guidelines for Nonferrous Scrap, Ferrous Scrap, Glass Cullet, Paper Stock, Plastic Scrap." These specifications have been established and copyrighted by the Institute of Scrap Recycling Industries, Inc. (ISRI), 1325 G Street NW, Suite 1000, Washington, DC 20005. The English version of the specification is to take precedence over translated versions. The ISRI Scrap Specifications Circular is subject to change. Readers should contact ISRI to make certain they are reading the most recent version of the Scrap Specifications Circular or access the ISRI Web site (www.isri.org) to verify the most recent version of the Scrap Specifications Circular.

Steel From Scrap Tires

General Guidelines

Items not covered in the specifications, and any variations in the specification, are subject to special arrangement between buyer and seller. Percentages listed below are by weight.

Preparation

Consumer and supplier to agree upon preparation for transport, such as the following:

Loose – Whole

Loose – Chopped. If wire is chopped or shredded, parties may wish to specify the means of processing and/or characteristics of the final product (density, length of pieces, etc.).

Baled

Bales of wire should maintain their form during loading, shipment, unloading, storage, and handling typical of that done at a consuming facility, unless otherwise specified.

> **Baled – High Density.** Hydraulically compressed, no dimension larger than 24", density of at least 75 pounds per square foot.
>
> **Baled – HRB/Low Density.** Density of less than 75 pounds per square foot. Each bale secured with sufficient number of bale tires drawn tight to insure a satisfactory delivery.

Other Means of Preparation. Individual specifications to be agreed upon between consumer and supplier.

ISRI Code No.	Item
272	**Pulled bead wire (Truck) – Grade 1**. Not chopped; made up of loops of wire. Less than five percent (<5%) rubber/fiber.
273	**Pulled bead wire (Truck) – Grade 2**. Not chopped; made up of loops of wire. Five to ten percent (5–10%) rubber/fiber.
274	**Pulled bead wire (Truck) – Grade 3.** Not chopped; made up of loops of wire. Greater than ten percent (>10%) rubber/fiber.
275	**Pulled bead wire (Passenger) – Grade 1**. Not chopped; made up of loops of wire. Less then five percent (<5%) rubber/fiber**.**
276	**Pulled bead wire (Passenger**) – **Grade 2.** Not chopped; made up of loops of wire. Five to ten percent (5–10%) rubber/fiber.
277	**Pulled bead wire (Passenger) – Grade 3**. Not chopped; made up of loops of wire. Greater than ten percent (>10%) rubber/fiber.
278	**Processed tire wire (Ferrous) – Grade 1**. Chopped. Less than two percent (<2%) rubber/fiber.
279	**Processed tire wire (Ferrous) – Grade 2**. Chopped. Less than five percent (<5%) rubber/fiber.
280	**Processed tire wire (Ferrous) – Grade 3**. Chopped. Five to ten percent (5–10%) rubber/fiber.
281	**Processed tire wire (Ferrous) – Grade 4**. Chopped. Ten to twenty percent (10–20%) rubber/fiber.
282	**Processed tire wire (Ferrous) – Grade 5.** Chopped. Greater than twenty percent (>20%) rubber/fiber.

Appendix F.
Survey Response Table

Summary Counts of Survey Responses

Item	All Qty	All Percent		California Qty	California %	Rest of U.S. Qty	Rest of U.S. %	International Qty	International Percent
Mailed	*1104*			*287*		*710*		*107*	
Returned by PO	*49*	**4.4%**	a)	*19*	**6.6%**	*24*	**3.4%**	*7*	**5.6%**
Eliminated for other reasons	*142*	**12.9%**	a)	*43*	**15.0%**	*84*	**11.8%**	*15*	**14.0%**
(bad #s, dupes, etc)									
	191	**17.3%**	a)	62	**21.6%**	108	**15.2%**	22	**19.6%**
Net Surveys Mailed (less those returned by PO, and less those eliminated for other reasons)	*913*	82.7%		*225*	78.4%	*602*	84.8%	*85*	80.4%
Total Completed Surveys	*425*	**46.5%**	b)	*123*	**54.7%**	*279*	**46.3%**	*23*	**29.1%**
Of completed, those that had valuable data	*245*	***57.6%***		*46*	***37.4%***	*179*	***64.2%***	*20*	***80.0%***

[a] % of total mailed

[b] % of net no. mailed

Appendix G.
Contacts and Sources of Information From Supply and Demand Analysis

1. Advanced Highway Maintenance and Construction Technology Research Center, University of California, Davis, CA 95616-5294, 530-752-5981.

2. American Association of State Highway and Transportation Officials, *Report on the 1990 European Asphalt Study Tour*, June 1991, p. 168.

3. American Excelsior Company, Erosion Technical Support, PO Box, 5067, Arlington, TX 76005, 800-777-SOIL.

4. American Metal Market, "AMM Scrap Iron & Steel Prices," January 30, 2003, p.10.

5. Beard, D., "Polyester Fiber as a Molded Material," *Total Innovative Manufacturing*, May 20, 2002, p. 27.

6. Bulluck III, L.R. and J.B. Ristaino, "Effect of Synthetic and Organic Soil Fertility Amendments on Southern Blight, Soil Microbial Communities and Yield of Processing Tomatoes," Publication No. P-2001-1214-01R, The American Phytopathological Society, January 14, 2001, 92 (5): 181–189 (2002).

7. California Department of Transportation (Caltrans), Division of Engineering Services, 1801 30th Street, Sacramento CA 95816-8041, Translab, New Products Coordination (Don Fogle), Chief Paving Scientists (Hamid Moussavi and Tom Pile), 916-227-7000.

8. California Department of Transportation, *Standard Specifications,* July 1999, p. 825.

9. California Integrated Waste Management Board, *Five-Year Plan for the Waste Tire Recycling Management Program: Fiscal Years 01/02--05/06* (620-03-007).

10. California Integrated Waste Management Board, *Five-Year Plan for the Waste Tire Recycling Management Program: Fiscal Years 03/04--07/08* (620-03-007).

11. Carpet Cushion Council, PO Box 546, Riverside CT 06878, Mr. William H. Oler, Executive Director, 203-637-1312.

12. Composite Fabrication Association, 1655 N Fort Meyer Drive, Suite 510, Arlington, VA 22209, Bob Lacovara, 703-525-0511.

13. Conrad, Randall & Associates, Ltd., *The Market Feasibility of Recycling/Recovering Post Consumer Polypropylene Baler Twine in Alberta*, March 15, 2000, p. 47.

14. Consolidated Textiles, 8100 South Blvd, Charlotte NC 28273, Bob Zelinski, 800-243-8621.

15. Federal Highway Administration, U.S. Department of Transportation, "Recycled Materials in European Highway Environments: Uses, Technologies, and Policies," October 2000, p. 134.

16. Fiberand Corporation, 7150 SW 62nd Avenue, South Miami, FL 33143, Mark Ellis, 305-661-4506.

17. Geosynthetic Materials Association, 1801 County Road B W, Roseville, MN 55113-4061, Danette Fettig, Managing Director, 800-328-4324.

18. The Goodyear Tire and Rubber Company, 1144 E Market St, Akron OH 44316, "Scrap Tire Recovery," October 9, 2001, p. 20.

19. Industrial Fabrics Association International, 1801 County Road B W, Roseville, MN 55113-4061, 800-636-5054.

20. Market Development Alliance of the FRP Composites Industry, 600 Mamaroneck Avenue, 4th Floor, Harrison, NY 10528, John P. Busel, 914-381-3572, fax: 914-381-1253.

21. National Asphalt Pavement Association, 5100 Forbes Blvd., Lanham, MD 20706, 888-731-4821.

22. Office of Waste Reduction, North Carolina Division of Pollution Prevention and Environmental Assistance, *Waste Reduction Fact Sheet: Cotton Fiber Processing Waste*, OWR-95-20, June 1995.

23. Reliance Products Division, Reliance Upholstery Supply, Oakland, CA, Marcelo Buenas, 510-893-7687.

24. ReSyk, Inc., 1755 N 2000 West, Brigham City, UT 84302, Chris Brough, 435-723-2950.

25. Richmond Steel Recycling Ltd., Richmond, BC V6V 1T7, CANADA, John Ray, 800-354-5263.**

26. Rubber Manufacturers Association, "Energy Recovery From Scrap Tires," May 2002, p. 1.

27. Rubber Pavement Association, 1801 S Jentilly Lane, Suite A-2, Tempe, AZ 85281, Doug Larson, 480-517-9944.

28. Rutherford Sales & Recovery, Forest City NC, Steve Stroud, 828-245-6060.**

29. Schnitzer Steel Industries (General Metals), 1902 Marine View Drive, Tacoma WA, 800-562-9876, 253-572-4000.**

30. Schroeder, R.L., "The Use of Recycled Materials in Highway Construction," *Public Roads*, v. 58, No. 2 (Autumn 1994), pp. 32–41.

31. Seal Coating Inc., "Random-Crack Sealing by Fiber Reinforced Method," June 14, 1999, pp. 1–2.

32. Secondary Materials and Recycling Textiles Association, 7910 Woodmont Avenue, Suite 1130, Bethesda, MD 20814, 301-656-1077.

33. Stabilizer Solutions, 205 S 28th Street, Phoenix, AZ 85034, John Hubbs, 800-336-2468.

34. Suppliers of Advanced Composite Materials Association, 1606 Wilson Blvd, Suite 901, Arlington, VA 22209, 703-841-1556.

35. Target Recycling, Inc. Ring Road #1, Chemainus, BC V0R 1K0, CANADA, 250-246-4403.*

36. Taylor, B., "Same Tired Story?," *Recycling Today*, 37 (5):33-42, May 1999.

37. TCB Material Reclamation, Menlo Park CA, Lee Notrowich, 650-326-9700.

38. *Technical Bulletin: Use Of Crack Sealing Prior To Placement Of Hot Mix Asphalt*, Flexible Pavements of Ohio, March 29, 2001, pp 1-3.

39. Textile Fibers & By-Products Association, 1531 Industrial Drive, Griffin, GA 30224, C.E. Williams, Executive Secretary, 770-412-2325.

40. Trex Company, LLC, 160 Exter Drive, Winchester, VA 22603-8605, 800-Buy-TREX.

41. Turbo Technologies, Inc., 1500 First Avenue, Beaver Falls, PA 15010, 800-822-3437.

42. U.S. Geological Survey, 989 National Center, Reston, VA 20192, David Gibson, 703-648-7963, fax: 703-648-7975.

43. Western Rubber Products, Ltd., New Westminster, BC, CANADA, Peter Phillips, 604-521-5203.*

44. www.afsinc.org/ (American Foundry Society).

45. www.asphaltinstitute.org/ (Asphalt Institute).

46. www.carpet-rug.com/ (The Carpet and Rug Institute).

47. www.dupont.com/fiberfill (E.I. du Pont de Nemours and Company, Dacron Fiberfill).

48. www.eapa.org (European Asphalt Paving Association).

49. www.ectc.org (Erosion Control Technology Council).

50. www.inda.org (Association of Nonwoven Fabrics Industry).

51. www.infoplease.com/ (U.S. Bureau of the Census)

52. www.mdacomposites.org (Market Development Alliance of the FRP Composites Industry).

53. www.npg.org/states/ca.htm (Negative Population Growth).

54. www.steelonthenet.com/ (online access to news, analysis and statistics on the iron and steel industry).

55. www.textilerecycle.org (Council for Textile Recycling).

56. www.worldofconcrete.com (World of Concrete).

*Tire Processors

** Scrap Steel or Fiber Dealers